HELSINGIN YLIOPISTO
HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

# The Emergence of Students' Transformative Agency in a Novel Design and Making Environment

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Tuija Cornér

Supervisors: Anu Kajamaa &
Kristiina Kumpulainen

HELSINGIN YLIOPISTO

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Tiivistelmä - Referat – Abstract

New digital learning environments challenge traditional learning concepts by emphasizing student agency and collaboration (Ito, 2013; Kumpulainen, Kajamaa & Rajala, 2018). This study addresses the expressions of students' transformative agency, and the role of tools in its emergence, in a novel design and making environment called the FUSE Studio. Research on transformative agency has traditionally focused on intervention research related to adults, and in particular on working life, and there has been little research on students' transformative agency (Kajamaa & Kumpulainen, 2019). The types of transformative agency identified by Haapasaari and colleagues (2016) were used as the theoretical frame of reference for the study (Haapasaari, Engeström & Kerosuo, 2016). In addition, the concepts of the social object of Kumpulainen and Kajamaa (2019) and the double stimulation of Vygotsky (1978) were utilized when analyzing the role of tools (Kumpulainen & Kajamaa 2019; Vygotsky 1978). The data consisted of 75 hours of video material collected by filming the work of 9–12-year-old students (N=94) in the novel design and making environment in the fall of 2016. The data were analyzed using the types of transformative agency (resisting, criticizing, explicating new possibilities or potentials in the activity, envisioning new patterns or models of the activity, committing to new actions, and taking consequential actions to change the activity) of Haapasaari and colleagues (2016) as reference. The role of tools in mediating students' transformative agency was analyzed in connection to the features of the types of transformative agency identified in the first research question. Expressions of students' transformative agency were found in the data for all six types. Students' agentive actions were expressed both verbally and physically, often using the tools in the challenges. Students' transformative agency manifested itself both in opposing activities, which manifested as playing or disruptive behavior, and in creating new activities that pursued students' own interests, which manifested as extending the challenges. The tools inspired and facilitated the emergence of students' transformative agency.Students use both verbal and bodily expressions to break away from the given frame of action set by the learning environment. Working with tools both inspires and facilitates students' efforts of breaking away, which sometimes leads to unexpected design and making activities.



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muutostoimijuus, maker-pedagogiikka, digitaaliset oppimisympäristöt, värkkääjäpaja

Keywords

transformative agency, maker education, digital design and making environments, makerspace

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Tiivistelmä - Referat – Abstract

Uudenlaiset digitaaliset oppimisympäristöt haastavat perinteisiä oppimiskäsityksiä korostamalla oppilaiden osallisuutta ja yhteistyötä (Ito, 2013; Kumpulainen, Kajamaa & Rajala, 2018). Tämä tutkielma käsittelee oppilaiden osoittamia muutostoimijuuden ilmentymiä sekä välineiden roolia muutostoimijuuden kehittymisessä uudessa maker-oppimisympäristössä. Muutostoimijuuden tutkimus käsittelee perinteisesti aikuisten työelämään liittyviä interventiotutkimuksia ja oppilaiden muutostoimijuutta on tutkittu vain vähän (Kajamaa & Kumpulainen, 2019). Tutkimuksen teoreettisena viitekehyksenä käytettiin Haapasaaren ja kumppaneiden tunnistamia muutostoimijuuden tyyppejä (Haapasaari, Engeström & Kerosuo, 2016). Lisäksi välineiden roolia tarkasteltaessa hyödynnettiin Kumpulaisen ja Kajamaan (2019) sosiaalisen objektin, sekä Vygotskyn (1978) kaksoisstimulaation käsitteitä (Kumpulainen & Kajamaa 2019; Vygotsky 1978). Tutkimusaineisto koostui 75 tunnista videomateriaalia, joka on kerätty videoimalla 9–12 vuotiaiden oppilaiden (N=94) työskentelyä uudessa maker-oppimisympäristössä (FUSE Studio) syksyllä 2016. Aineisto analysoitiin Haapasaaren ja kumppaneiden (2014) muutostoimijuuden tyyppien (vastustaminen, kritisoiminen, toiminnan uusien mahdollisuuksien analysointi, toiminnan uusien muotojen tai mallien visualisointi, konkreettisiin muutostoimiin sitoutuminen ja seuraavien askelten ottaminen) pohjalta. Välineiden roolia analysoitiin yhteydessä ensimmäisessä tutkimuskysymyksessä tunnistettuihin muutostoimijuuden tyyppien ilmentymien kategorioihin. Aineistosta löydettiin oppilaiden muutostoimijuuden ilmaisuja kaikkiin kuuteen tyyppiin liittyen. Oppilaat ilmaisivat toimijuustekoja sekä sanallisesti että kehollisesti, usein haasteisiin kuuluvia välineitä käyttämällä. Oppilaiden muutostoimijuus ilmeni sekä toiminnan vastustamisena, mikä näkyi leikkimisenä tai muita oppilaita häiritsevänä käytöksenä, että uuden, oppilaiden omia mielenkiinnonkohteita tavoittelevan, toiminnan luomisena mikä näkyi yhteistoiminnallisena haasteiden laajentamisena. Työkalut innoittivat ja avittivat oppilaiden muutostoimijuuden kehittymistä. Pyrkiessään irtautumaan oppimisympäristön asettamasta toimintakehyksestä, oppilaat käyttävät sekä sanallisia, että kehollisia ilmaisuja. Välineiden käsittely sekä innostaa että avittaa oppilaiden irtautumispyrkimyksiä, jotka toisinaan johtavat ennalta-arvaamattomiin design- ja making-toimintoihin.



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# 1 Introduction

In a rapidly changing world, the empowerment of the individual, and of communities in particular, is pivotal (Engeström et al., 2016). By emphasizing, among other things, student participation, thinking and problem-solving skills, information and communication technology skills, and entrepreneurship, which are learned through and across subjects in varied learning environments, the Finnish National Core Curriculum seeks to respond to the pressures for change (NCC, 2014).

The context of this study, the FUSE Studio, is a school-based makerspace, a novel design and learning environment taken into use in the school under study to respond the implementation of the new core curriculum. In the FUSE Studio, the students learn 21st century skills, such as critical thinking, creativity and collaboration skills, through activities in STEAM (i.e. Science, Technology, Engineering, Art and Mathematics) areas. The FUSE Studio consists of challenges such as designing and 3D printing jewelry, designing houses with 3D modelling software, and building ball tracks and solar powered vehicles. The challenges level up like video games, some of them being completely digital and others requiring the use of physical materials or tools. The aim of this studio is to enhance a student's interest-driven, collective and inclusive learning. This is reflected in that students get to choose not only the challenges they work on but also who they work with and where. Students also do not have to wait for the teacher to assess their progression, but self-document their challenge completion on the platform. (Hilppö & Stevens, 2020; Stevens et al., 2016.) The FUSE Studio brings the goals of the National Core Curriculum to a practical level.

With this study I aim to illustrate the expressions of transformative agency the students show while working in the FUSE Studio. I define transformative agency as "breaking away from given frame of action and taking initiative to transform it" (Virkkunen, 2006, 49). By challenging the existing instructions, students pursue new design and making activities that meet their interest and create opportunities

for meaningful learning. There is relatively little research on students' transformative agency (for an exception see: Kajamaa & Kumpulainen, 2019), so with this study I will contribute to expanding the existing research and provide new insights into students' voluntary activities as well as into how tools help to mediate students' change acts.

In addition to existing literature on children's agency (Kajamaa & Kumpulainen, 2019; Kumpulainen & Kajamaa, 2019; Kumpulainen, Kajamaa and Rajala, 2018; Rainio, 2010; Hilppö et al., 2016; Wood 2014), this study has been inspired by research on adults' transformative agency in formative interventions, such as the Change Laboratory (Haapasaari, Engeström & Kerosuo, 2016; Sannino, Engeström & Lemos, 2016; Virkkunen 2006; Kerosuo, Kajamaa & Engeström, 2010). Six types of transformative agency, namely resisting, criticizing, explicating new possibilities, envisioning new patterns of models of the activity, committing to concrete actions aimed at changing the activity and taking consequential actions to change the activity, have been identified in research conducted in the context of Change Laboratory interventions (Engeström, 2011; Haapasaari et al., 2016). I will apply these types in this study. However, it should be noted that this is not an interventionist study; the expressions of students' transformative agency have been identified through video without interfering with their activities.

# 2 Maker education

In this chapter, I will describe maker education and makerspaces, with the goal on conceptualizing the frame of reference to which the context of this study, the FUSE Studio, relates. I will focus on student agency in maker education and then present the core design features of the FUSE Studio. Finally, I describe the manifestations of student transformative agency in the FUSE Studio.

## 2.1 Maker education and makerspaces

According to Bevan, Gutwill, Petrich and Wilkinson (2014), making is linked to promoting entrepreneurship, advancing science, technology, engineering and mathematics (STEM), and enabling inquiry-based learning experiences. (Bevan, Gutwill, Petrich & Wilkinson, 2014). The letter A, representing arts, was later added to STEM, turning it into STEAM, with the aim of generating new understanding between disciplines and to increase inclusiveness and accessibility (Peppler & Wohlwend, 2018).

Martin (2015), defines making in education as “an activity related to design, construction, and modification that is directed at making a “product’’ of some sort that can be used, interacted with, or demonstrated.” The activity often uses traditional hobby techniques, such as sewing, combined with digital technologies, such as 3D printers. (Martin, 2015, 31.) At a more general level, maker movement refers to an activity in which people interested in a particular topic, such as hobbyists, tinkerers, and artists, creatively produce new content, practices, or products by experimenting and sharing. (Martin, 2015; Halverson & Sheridan, 2014). According to the Maker Movement Manifesto proposed by Mark Hatch (2014), CEO and cofounder of TechShop, maker movement is based on nine ideas: make, share, give, learn, tool up, play, participate, support and change (Hatch, 2014).

Halverson and Sheridan (2014) consider making, that refers to activities that focus on “engaging participants in learning content and process”, makerspaces, where learning isn’t regulated but “happens as a consequence of individuals beginning as legitimate peripheral participants and moving toward becoming full participants”, and maker, that refers to “identities of participation”, as three relevant components of maker movement regarding maker education. (Halverson & Sheridan, 2014, 501–502.) Martin (2015), on the other hand, uses the terms of digital tools, which includes physical and logical digital tools, community structure, which includes both online and in-person spaces, and the maker mindset, which includes the beliefs and values within the community, to describe the key elements of the Maker movement from an educational perspective (Martin, 2015). In the view of Halverson and Sheridan (2014), maker education exists between formal education and informal learning environments, drawing qualities from both, and drives the discussion forward where and how learning takes place. (Halverson & Sheridan, 2014).

Maker education involves the assumption of the construction of knowledge through experimentation and through failure in social communities (Martin, 2015; Halverson & Sheridan, 2014; Hilppö & Stevens, 2020). The theoretical background of maker education is influenced by constructivism, according to which the learner actively creates and develops his/her knowledge structures through experience (Kumpulainen, 2017; Bevan et al., 2014; Halverson & Sheridan, 2014).

With the use of digital tools and technologies, Papert’s idea that the physical construction of an object promotes learning, is extended and updated in modern makerspaces (Bevan & WIkinson, 2014). Seymour Papert (1980), applied Piaget’s theory of knowledge construction as he studied children’s learning through computer-based programs. Piaget distinguishes between concrete and formal level thinking that begins to develop at around the age of 12. According to Papert, formal information can be concretized with the help of computers. In that case, information that previously required the ability to think formally would be available earlier with the help of computers. However, Papert points out that computers

should not be allowed to program a child, that is, to provide children with mainly mechanical tasks. Instead, the child should control the computer, allowing the child to learn to be an expert in the tool and strengthen his or her personal relationship with science, math, and building intellectual models. (Papert, 1980.)

Makerspaces are digitally enhanced learning environments in which individuals with different levels of expertise develop digital or physical objects according to their own interests and ideas (Sheridan, Halverson, Litts, Brahms, Jacobs-Priebe & Owens, 2014). Learning-by-doing and the possibility to play with materials bring individuals together for creative and collaborative work (Kumpulainen, 2017). In their study of makerspaces as learning environments, Sheridan and colleagues (2014) found that what is valued in makerspaces, is the "*process* involved in making–in tinkering, in figuring things out, in playing with materials and tools." This was reflected, for example, in the fact that participants might have several unfinished projects that they could not complete, or in the fact that they, without having any project in mind, fooled around with the tools. (Sheridan et al., 2014, 528.)

Learning in makerspaces is not is not regulated (or guaranteed) but happens "as a consequence of individuals beginning as legitimate peripheral participants and moving toward becoming full participants" (Halverson & Sheridan, 2014, 502). An essential element in makerspaces, is that the work is voluntary and that individuals decide themselves, when, how and if they want to work and they should be able to move in and out of spaces at their will. This creates a tension between formal and maker education. Moreover, in makerspace practice traditional disciplinary boundaries created for curriculum by research in school are inauthentic. Instead, making, that connects traditionally separate disciplines, such as sewing and electronics, is supported in makerspaces (Sheridan et al., 2014.) According to Kumpulainen (2017), alongside processes of technology mediated artifact creation, making activities also contribute to emotional, relational and cultural processes (Kumpulainen, 2017).

## 2.2 Agency in maker education

Describing different levels of agency manifestations, Bevan and colleagues (2016) distinguish three types of educative making: assembly, which refers to projects where students work on step-by-step materials to create nearly identical objects, creative construction, in which tasks are set in the form of a challenge or a customizable model, allowing students to use their creativity by influencing certain elements of an object, such as appearance or functionality, and open-ended inquiry, sometimes called tinkering, which refers to projects of which students work on their own idea using creative problem-solving. Within open-ended inquiry, the created objects are very different from each other as they have been developed for a unique purpose. At the core of tinkering are the breakthroughs experienced by students, which are achieved by developing students' personally relevant ideas and overcoming difficulties in the generative process. (Bevan et al., 2016.) With combining the use of high- and low-tech tools in an open-ended design process emphasizing creative problem-solving, tinkering "has the potential to augment rather than replace familiar and powerful practices that students already possess". (Blikstein, 2013, 209).

In their study of tinkering programs designed for museum visitors, Bevan and colleagues (2014) identified four learning dimensions supported by tinkering: engagement, initiative and intentionality, social scaffolding, and development of understanding. Indicators for learners' *engagement* were spending time in tinkering activities that was manifested in learner's playing, envisioning, making, exploring materials and trying this over and over, and displaying motivation or investment through affect or behavior that was expressed in learners' showing emotions and remaining after they seemed "finished" to start something new. Indicators for *initiative and intentionality* were setting one's own goals, seeking and responding to feedback, persisting to achieve goals in the problem space and taking intellectual risks and showing intellectual courage. Initiative and intentionality were manifested, among other things, as learners' planning steps for future action and de-

veloping unique strategies, tools, objects or outcomes. Indicators for *social scaffolding* were requesting and offering help in solving problems, inspiring new ideas or approaches and physically connecting to other's works. Manifestations for social scaffolding included, but were not limited to, requesting or offering ideas and approaches, offering tools or materials in service of an idea and innovating and remixing or modifying other's ideas or strategies. Finally, indicators for *development of understanding* were expressing a realization through affect or utterances, offering explanations for a strategy, tool or outcome, applying knowledge and striving to understand. Development of understanding was manifested, among other things, in learners showing excitement when expressing a realization, offering or refining explanations for a strategy, tool or outcome, possibly by testing and re-testing, connecting to prior knowledge, including STEM concepts, employing what they have learned during their explorations, and remaining in the problem space to explore their confusion and to build an understanding. (Bevan et al., 2014, 7–8.) In the same vein, Resnick, Berg and Eisenberg (2000) found that when students designed and built their own scientific instruments they were more personally invested in their scientific investigations and were able to "develop deeper critical capacities in evaluating scientific measurements and knowledge" (Resnick, Berg & Eisenberg, 2000, 7). Kafai, Fields and Searle (2014) urge students to take up active roles in deciding what to create and how, as well as persist through challenges of the design process. This way students can emerge from consumers to producers of technology. (Kafai, Fields & Searle, 2014). In this study, the focus is in investigating students' transformative agency in a digitally enhanced, novel makerspace context named the FUSE Studio.

## 2.3 The FUSE Studio as a digital design and making environment

The FUSE Studio is a novel design and making environment developed in the School of Education and Social Policy at Northwestern University in Chicago, the United States. FUSE seeks to engage students in creative production, collaboration and problem solving by providing them with STEAM (science, technology,

engineering, arts and design) related challenges (Penney, 2016; Ramey, 2017; Hilppö & Stevens, 2020). In the FUSE Studio, students are empowered to choose the challenges they want to work on while also growing relative expertise (Champion, Penney & Stevens, 2016).

### 2.3.1 Core design features of the FUSE Studio

There are five core design features behind the development of the FUSE Studio. First, students choose, which guides all activity in the FUSE Studio. Students choose the challenges they want to work on, where they want to work, if they want to work alone or in groups and when to stop working. (FUSE Studio, 2020; Hilppö & Stevens, 2020; Stevens et al., 2016.) Second, the challenges are designed to meet the students' interests in music, design, and pop culture. The aim is to break down the silos of traditional STEM disciplines by inventing new learning environments that provide students with personally meaningful experimentation. Later, arts were included to emphasize design as a part of mathematics and science. Third, teachers take the role of facilitators. Teachers themselves are novices in regard to the new learning environment, so instead of having all the answers, they stand alongside the students as problem solvers or help the learners move forward with questions. (FUSE Studio, 2020; Stevens et al., 2016., Penney, 2016.) Fourth, students learn from each other. According to Champion, Penney and Stevens (2016), students' relative expertise and agency is supported as working in the FUSE Studio emphasizes collaborative, peer-based learning that is guided by students' choice (FUSE Studio, 2020; Champion, Penney & Stevens, 2016). Finally, failure is just another try, which means that there are no negative consequences from failure, so students accept failure as part of the process and try again. (FUSE Studio, 2020; Hilppö & Stevens, 2020).

### 2.3.2 Student transformative agency in the FUSE Studio

The FUSE Studio is designed to support the student's freedom of choice, which is reflected, among other things, in the students' ability to choose which challenges to solve and with whom. (Hilppö, 2020; Stevens et al., 2016.) Hilppö, Stevens, Jona, Echevarria and Penney (2016) studied productive deviations, manifestations of student agency originally theorized by Rajala and Sannino (2015). They found, that while working in the FUSE Studio, students went beyond deviating from the instructions and actually realized the extensions they had envisioned. (Hilppö, Stevens, Jona, Echevarria & Penney, 2016.) Empowering students with choice builds “shareable knowledge resources” as the accumulation of differentiated knowledge is advanced and the students are allowed to develop relative expertise, that is, become more knowledgeable than their peers. (Champion, Penney & Stevens, 2016, 1028).

Ramey and Stevens (2019) researched interest development in the context of FUSE Studio, an educational makerspace, by following the building of one student’s interest pathway. The student developed and pursued an interest to 3D printing an entire school year. During the school year, not only she gained expertise on 3D printing, but also learned many multidisciplinary STEM-related skills, for example troubleshooting, mathematical and spatial reasoning and collaboration and negotiating skills. They argue that the context of FUSE, as opposed to an open-ended makerspace, allowed the student to pursue her interest by not only providing the tools but also support in scaffolding on how to use them. They also refer to previous studies that point out that the student’s interests can be sparked by other things than the topic itself, as was the case in their study: instead of the challenges the printer itself was more interesting to the student. (Ramey and Stevens, 2019.)

# 3 Understanding transformative agency

In this chapter, I will introduce the multidimensional concept of agency. After the description of agency research, the review of existing research focuses on the concept of transformative agency. I will present the role of tools as mediators of agency subsequently.

## 3.1 Approaches to studying agency

Depending on the research tradition, the notion of agency gets different, sometimes conflicting definitions. The origin of the concept of agency is in the social sciences (e.g. Giddens, 1984) but the term has also been used in psychology (e.g. Bandura, 2006), anthropology and gender research (Eteläpelto, Vähäsantanen, Hökkä & Paloniemi, 2013; Rainio 2010). Further, Rainio (2010) identifies five contradictory elements of agency; continuity and contingency, dependence and separateness, simultaneous need for mastery and submission, passive and active manifestations of agency and lastly the simultaneous need for control and promotion of agency in an educational relationship (Rainio, 2010). Basically, according to Lipponen and Kumpulainen (2011), agency means that people are able to influence their own lives by intentionally acting in a way that conveys their "will, autonomy, freedom and choice" (Lipponen & Kumpulainen, 2011, 812). Furthermore, the material and social reality is enhanced with imagination, art and play, that expand our potential (Rainio, 2010).

In social science discussion, agency is understood to be inseparable from social structures, such as social class, gender, race and occupational conditions (Eteläpelto et al., 2013; Giddens, 1984). Giddens (1984), as a representative of the approach, views agency through intentionality. A person's acts are agentive, when he or she could have acted in a different way and without the person's intervention, the thing that happened wouldn't have happened. In addition, agency is associated to power as "to be an agent is to be able to deploy (chroni-

cally, in the flow of daily life) a range of causal powers, including that of influencing those deployed by others". Giddens introduces a notion of duality of structure, where structural properties of social systems are not external to individuals but at the same time the instrument and result of the repetitively organized practices. (Giddens, 1984, 14.)

Bandura (2006) agrees with Giddens that people, by acting intentionally, create social systems and these in turn affect people's lives. According to Bandura's individualistic conception of agency, the foundation of human agency is the belief of personal efficacy, that is, a belief that a person can bring about change through his or her own actions. Efficacy beliefs affect people's expectations, goals and how they respond to challenges and adversities. A person with high efficacy stays resilient when facing difficulties and believe that with perseverance and improvement of self-regulatory skills, adversity is overcome. In contrast, a person with low efficacy quickly give up trying, when facing difficulties. Thus, self-efficacy affects whether people think in a self-enhancing or self-debilitating ways and how likely they consider different potential outcomes. With the impact social environments have on promoting certain competencies, values and lifestyles, self-efficacy can have a determining influence on the decisions people make and the directions of their lives. (Bandura, 2006.)

Davies (1990) states, that agency requires discursive, personal and social resources. Discursive resources allow the individual to be a meaning-making, engaged and active participant in the collective that they are part of. The individual should also have access to the kind of discursive practices that don't limit their positionings but enable different perspectives and ways of being to emerge. Moreover, personal resources refer to the individual's wish of being agentic, their skills and knowledge resources as well as "the ability to mobilize the relevant discourse". Social resources emphasize "access to interactive others" as recognizers of individual's agency. (Davies, 1990, 359–360.) Davies approaches agency from the post-structural point of view, but as noted by Eteläpelto and col-

leagues (2013), some socio-cultural notions of agency resemble post-structuralism, in that they see the individual's agentic actions inseparable from the social context (Eteläpelto et al., 2013).

In this study, agency is approached from a socio-cultural perspective. In the socio-cultural framework, the key elements for mediating human activities are socio-cultural contexts and the tools and objects in them (Eteläpelto et al., 2013; Hilppö, 2016). According to Lipponen and Kumpulainen, "agency work is seen [in the socioculturally oriented research tradition] as a dynamic process that is constructed relationally in interaction within a cultural context, involving ongoing transformations of both the community and the self. Furthermore, through dialogue that agency is constructed, contested, negotiated and, re-negotiated." (Lipponen & Kumpulainen, 2011, 813).

Kumpulainen, Kajamaa and Rajala (2018), studied agency-structure dynamics in a novel design and making environment, the same digitally enhanced learning environment that is the focus of this study, from socio-cultural perspective, applying Engeström's (2007) conceptualization of stabilization knowledge and possibility knowledge (Kumpulainen, Kajamaa & Rajala, 2018). Stabilization knowledge refers to reality freezed still for easier investigation. Possibility knowledge in turn, is agentive, destabilizing, knowledge that opens up possibilities by putting it in movement. (Engeström, 2007). In the study, Kumpulainen and colleagues mirrored institutionalized structures in school (i.e. stabilization knowledge) to novel emerging practices (i.e. possibility knowledge). They identified three clear agency-structure dynamics, namely maintaining existing patterns of activity, breaking away from existing patterns of activity, and collective uptake of new patterns of activity. The introduction of the novel design and making environment created tension between the new forms of teaching and learning and the traditional activity of doing school. This led to a boundary space being created where the teachers and the students were sometimes able to explore beyond stabilization knowledge towards possibility knowledge. (Kumpulainen et al., 2018.)

On the relationship between the social and individual, researchers have dissenting views. Eteläpelto and colleagues (2013) have reviewed the concept of agency, especially what does professional agency at work mean in different research traditions, and have roughly divided the socio-cultural approach into two sub-approaches in terms of how they relate to individual agency: object oriented activity-theoretical notions and subject oriented developmental approaches. (Eteläpelto et al., 2013.)

In the object-oriented theories the individual is seen subordinate to the surrounding society (Eteläpelto et al., 2013). Actually, Engeström (2005) points out that the weakness in most attempts to categorize different dimensions of agency, is that they emphasize the individual as the foundational agent thus overlooking the collective aspects of agency. He offers the cultural-historical activity theory (CHAT), developed by Leontiev, Vygotsky and Luria, and it's five principles, as a framework, to increase the potential for understanding change. The five principles of activity theory according to Engeström (2005) are: object-orientation, which refers to the object or the aim of the activity; mediation by tools and signs, which are used to initiate consequential action; mutual constitution of actions and activity, which brings together future-oriented activity-level envisioning and consequential action-level decision-making; contradictions and deviations as a source of change, which refers to activity system's continuous movement where contradictions cause new forms of activity to emerge, which can then manifest as innovative solutions; and historicity, which implies that in order to understand its potential, each activity system's history should be analyzed against its own history since activity systems take shape and transform over time. (Engeström, 2005.) Stetsenko (2006), takes a critical stance toward CHAT and argues that individual agency is the basis for social life and human development, therefore activity should be seen as a continuum consisting of material production of tools, people-to-people interaction and human subjectivity. (Stetsenko, 2005; Eteläpelto et al., 2013.)

In the subject oriented notions of socio-cultural approach, the relationship between the individual and the society is understood to be more interactive. The

social surroundings have an important role in the emergence of an individual's agency, but the influence of the individual's personal experience is not excluded. (Eteläpelto et al., 2013; Billett, 2006.) Furthermore, Eteläpelto and colleagues (2013) point out that agency is in constant motion varying over time and conditions and suggest that both the socio-cultural and discursive reality and the individual's interpretations and purposes should be considered while analyzing agency (Eteläpelto et al., 2013)

## 3.2 Transformative agency

The notion of transformative agency has roots in cultural-historical activity theory (CHAT), that emphasizes collective object-oriented actions over individual characteristics in the emergence of agency. (Haapasaari et al., 2016). Virkkunen (2006) defines individual transformative agency as "breaking away from given frame of action and taking initiative to transform it". (Virkkunen 2006, 49.) Breaking away, according to Engeström (2006), refers to "resolving or escaping a contradictory situation by means of constructing mediating artifacts that enable the subjects to master their own actions in a qualitatively new way" (Engeström, 2006, 28–29). Contradictions occur, when a new element, such as new tools or technology, is assumed by the activity system (Virkkunen, 2006). From these perceived contradictions, transformative agency emerges over time and interferences in joint activity, aiming for systemic change through "expansive transitions from individual toward collective actions" (Haapasaari et al., 2016, 233). The expanding cycles of learning and development are formed by alternating internalization of given cultural meanings and externalization of new ideas and solutions (Engeström, 2006).

Research on transformative agency is traditionally focused on the context of work and in formative interventions carried out in them (Kajamaa & Kumpulainen, 2019). Using Vygotsky's method of double stimulation as a basis, transformative agency can be built on and intentionally promoted in formative interventions (Engeström, 2011). Originally, double stimulation was used in experimental contexts to guide a child's problem-solving in a situation, where he was facing a task

that was beyond his capabilities and that he didn't have the skills to solve. The first stimuli, a neutral object, is placed near the child and is incorporated in the process of problem-solving. The second stimuli, that has a special function and is not necessarily given in a ready-made form, is offered simultaneously to be able to study the problem-solving process with the aid of "specific auxiliary means." (Vygotsky, 1978, 74.) External artifacts are used and developed so the people could control their actions and redefine a situation (Virkkunen, 2006). According to Engeström (2011), the role of the researcher in a formative intervention, is to arouse and maintain a participant-led expansive transformation process. The intervention starts when the participants face a contradictory object in central areas of their life. New concept is constructed by analyzing and expanding the object. Due to double stimulation as it's basis, promoting agency is a key part of the process. The aim is to produce novel concepts that can be applied in situations outside the intervention. (Engeström, 2011.) Used for organizational development, the Change Laboratory (CL) is an example of a formative intervention. During the CL process, the interventionist conducts cycles of discussions with the employees with the aim of promoting change in the workplace. (Engeström, Virkkunen, Helle, Pihlaja & Poikela, 1996; Virkkunen & Newnham, 2013; Kerosuo, Kajamaa & Engeström, 2010.)

Conducting research in a context of a central surgery unit, Engeström (2011) identified five main types of transformative agency from the Change Laboratory interventions, namely resisting, explicating new possibilities or potentials in the activity, envisioning new patterns of models of the activity, committing to concrete actions aimed at changing the activity and taking consequential actions to change the activity. By resisting, Engeström refers to criticizing, questioning, opposing or rejecting the interventionist or the management. Explicating can mean "relating to past positive experiences as evidence of unacknowledged potentials" (citing Sannino) or "characterizing the problematic object as a source of new possibilities". Envisioning can vary between tentative suggestions and introducing extensive designs. Committing is usually expressed with commissive speech acts or "agentive talk". The last type, taking consequential actions to change the activity, is self-explanatory as it means going beyond talk and actually making the

changes. (Engeström, 2011, 622–624.) Later, Haapasaari and colleagues (2016) added a sixth type, that they call criticizing. It is used to indicate the need for change in the current activity. (Haapasaari et al., 2016.)

Haapasaari and colleagues (2016), found all six types of transformative agency in CL sessions that were conducted in Itella Corporation, a service company that specializes in information and product flow management. To analyze the expressions of transformative agency, they used the components of an activity system; subject, object, tools, community, rules and division of labor, as a classification framework. Of these, the subject and the object of the activity system and the tools were the most frequently discussed topics connected to the expressions of transformative agency. The researchers were also interested in how the individual and collective agency were reflected in the process. They found that "an expression of transformative agency presented by one participant launched a series of further expressions of transformative agency, and the shared object was co-developed further". They argue that problems in the activity lead to a shared transformative agency among the participants. (Haapasaari et al., 2016, 252.) This is in line with Virkkunen's view, that agency becomes shared as people work together to explore a new form for a productive activity. (Virkkunen 2006). In conclusion, transformative agency is expansive by nature, developing over time, emerges from contradictions and is collectively actualized using mediating conceptual instruments (Haapasaari et al., 2016).

Expanding the application of the forms of transformative agency to research on students, Kajamaa and Kumpulainen (2019), studied the temporal dimension in the development of transformative agency in a novel digitally enhanced learning environment. This same digitally enhanced learning environment is also the focus of this study. They identified three types of indications of transformative agency: deviating, which refers to situations where the students criticized or resisted the instructions and with the use of mediating means and through interaction, expressed a wish to act in a different way; switching, which describes situations in which students take initiative to overcome the tensions; and transfiguring the

learning activity toward a shared goal. They found that the development of transformative agency was a non-linear process in which the manifestations of transformative agency "emerged and re-emerged, intertwined and overlapped in the students' design and making activities over time". (Kajamaa & Kumpulainen, 2019, 276.)

## 3.3 Tools mediating learning

An important principle of socio-cultural and cultural-historical activity theory is mediation by tools and signs (Vygotsky, 1978). For example, the Vygotsky's method of double stimulation described above is based on this principle. Engeström illustrates the principle with an example of an alarm clock as a mediating artifact that trigger consequential action. The conflict between work and rest is solved by using the alarm clock to wake up in the morning. Referring to Vygotsky, Engeström (2005) proposes that there are two phases in voluntary action: a design phase and an execution phase. A person controls his/her environment with the external activity of using tools and with that affects his/her own behavior. So higher psychological functions appear first in collaborative action (interpsychological) and then intrapsychological. (Engeström, 2005.) Tools are used to transmit social knowledge while being transformed during the activity itself. (Hmelo-Silver & Chernobilsky, 2004).

Social objects, introduced by Kumpulainen and Kajamaa (2019), refer to a change of a material object into common attention and meaning-making. They are described as "transactional, facilitating joint attention and productive exchanges among those who encounter them." Studying the concept in a context of an educational makerspace, namely the FUSE Studio, they found three interactional processes of material objects being turned to social objects "via joint attention and social interaction *about* the objects, *around* the objects and *with* the objects." In the first process, the students are, with the support of a teacher, testing and experimenting the FUSE Studio software. In this process, the students' joint attention was "established via social interaction *about* the material objects themselves". In the second process, social objects "brought the participants, both

students and teachers *around* the material objects of the makerspace to jointly observe, wonder, discuss and/or share." Non-verbal interactions often occurred in these situations. Sometimes, the students were brought *around* competing material objects, such as their phones, that they found more interesting than working on FUSE challenges. In the third process, "joint attention was established and maintained *with* the material objects". In this process, the material object's change into a social object was seen to mediate the students' commitment and possibilities for learning. (Kumpulainen & Kajamaa, 2019, 353–357.)

# 4 Research tasks and research questions

The aim of this study is to identify, analyze and describe students' emerging transformative agency in a novel design and making environment. In addition, the role of the tools in mediating the emergence of transformative agency is illustrated.

The research questions for this study are the following:

1. What types of expressions of transformative agency are found in the students' work in the FUSE Studio?
2. What kind of roles do tools play in the emergence of students' transformative agency in the FUSE Studio?

The research questions are answered by analyzing students' interaction in the FUSE Studio. The data consists of video material filmed at the researched school's FUSE Studio sessions.

# 5 Research context

In this chapter, I will introduce the school under study. Then, I will discuss the relationship of the FUSE Studio to curricula and describe the FUSE Studio as a learning environment.

## 5.1 The school in focus

The school in focus is a public comprehensive school that has 535 students of which 279 are boys and 256 are girls. The school consists of grade levels 1.–9. School starts at the age of seven (1st grade level) and the last primary level is 6th, then students are 12 years old. At the primary level there are 28 teachers. 8% of the students speak some other language than Finnish as a first language, Somali, Estonian, Russian and Arabic being the most common ones. Educational backgrounds of the families living in the neighborhood is as follows: basic education 24%, vocational training education 35% and higher education 41%. (Helsinki by District 2015.)

At the time of data collection, the government programme in Finland included a *knowledge and education* section, in which there were six spearhead projects. Regarding comprehensive school, the aim was to make Finland the leading country in modern and inspiring learning through the development of new learning environments and implementing digital materials. The introduction of the new National Core Curriculum for Basic Education (2014) was one step in achieving this goal. (Government Publications, 2018.) It states that “information and communication technology (ICT) is an integral part of varied learning environments. It strengthens students 'involvement and community work skills and supports students' personal learning paths. The development of learning environments takes into account a diverse media culture. New information and communication technology solutions are being introduced to promote and support learning.” (NCC, 2014, 29.)

The City of Helsinki implemented in 2016–2019 a digitalization program for education that supported the government's spearhead project. The ubiquity of learning, i.e., the expansion of learning outside the classroom to diverse learning environments, learner participation and inclusion, community, and future skills were the themes that served as the starting point for the program. More specifically, the school under study implemented the "school without textbooks" theme. (Helsinki Education Department, 2016.)

The curriculum of the school under study emphasizes design learning that involves developing and exploring operating models and ideas through creative problem-solving that breaks subject boundaries. An integral part of the design learning process is the circularly progressive design process that has four stages: observation and brainstorming; experimental, exploratory learning; learning by doing and developing ideas; and analyzing, communicating and sharing. (Local curriculum document, 2016[1].) According to The Finnish National Core Curriculum for Basic Education (NCC), schools should provide students with elective courses designed to deepen and broaden student competence according to student choice (NCC, 2014). In the school under study, the students can choose an elective course from the options offered by the school. The elective courses in arts and practical subjects, that include music, visual arts, crafts, physical education, and home economics, support the realization of the school's design focus. (Local curriculum document, 2016[2].) The FUSE Studio was introduced in the school under study in the fall of 2016 in response to the new curriculum requirements and the City of Helsinki's education digitalization program.

The FUSE Studio is an elective course offered in grade levels 4.-6. that promotes design learning. In the fall of 2016 three groups started FUSE sessions, one from each grade level. In the 4th grade group there were 32 students (22 boys and 10

[1] The text refers to the researched school's curriculum. The name of the school has been anonymized.

[2] The text refers to the researched school's curriculum. The name of the school has been anonymized.

girls), 30 students (19 boys and 11 girls) in the 5th grade group and in the 6th grade group 32 students (19 boys and 13 girls). A teacher in charge was assigned to each group and other teachers and teaching assistants worked with the groups as well. The teachers had had a two-day FUSE training, to which the teachers participated according to their own interests. The training was organized by FUSE team from USA. In the beginning of the course the FUSE sessions for the students were held once a week and were 45 minutes long. Later in the fall, the sessions were extended to 60 minutes. The students could choose to work in a computer lab (22 computers), a classroom or in the hallway. There were also laptops available and the materials for the challenges were kept in cabinets in the computer lab. The challenges could be worked on independently or in small groups chosen by the students themselves. The chosen challenge influenced the location and manner of work. Challenges that required more space and utilized physical materials, for example *Solar Roller* or *Coaster Boss*, were mostly worked in the hallway in groups, while software-based challenges, like *Dream Home or Ringtones*, were usually worked on independently either in the computer lab or in the classroom.

## 5.2 The FUSE Studio in relation to curricula

At the time of data collection, new core curriculum for basic education, that forms the basis of the cities' and schools' own curricula, had just been introduced in the fall of 2016. The new curriculum promotes transversal competence, that arise from the changes in the surrounding world. Transversal competence refers to a combination of knowledge, skills, values attitudes and will. Competence also means the ability to use knowledge and skills in a way that is appropriate to the situation. Students' attitudes, motivation and willingness to act are supported with feedback, guidance and support. Transversal competence is divided into seven competences and is learned through and across subjects. The competences are thinking and learning to learn; cultural knowledge, interaction and expression; taking care of oneself and others, managing daily life; multiliteracy; knowledge of information and communication technology (ICT); working life competences and

entrepreneurship; and participation, involvement and building a sustainable future. In addition, the new curriculum states that learning environments should be developed in such a way that they form a pedagogically diverse and flexible whole and offer opportunities for creative solutions for students to learn also outside school. Learning environments consist of both the spaces and places where learning takes place and the tools, services and materials used in learning. Promoting interaction, participation and building shared knowledge are features of a well-functioning learning environment. (NCC, 2014.)

Thinking and learning to learn; knowledge of ICT; and working life competences and entrepreneurship are extensively addressed in the FUSE section of the researched school's curriculum. Goals for thinking and learning to learn emphasize creativity, problem-solving skills and application of information from different sources. Students are also encouraged to cross existing boundaries by using their imagination in creative solutions. Students should recognize the importance of their own expertise in the collaborative knowledge-building process. ICT skills are being practiced by documenting and evaluating work and outputs and students are guided to use digital solutions effectively to reinforce the creative aspect of the learning process. Working systematically and on a long-term basis, students learn to take responsibility for what they do. Working life competences and entrepreneurship are practiced with project implementation and group work while encouraging students to identify their own strengths. (Local curriculum document, 2016[3].)

In the school under study, elective courses in arts and practical subjects, such as the FUSE Studio, are used to study visual arts and crafts to support the realization of the school's design emphasis. The learning objectives for arts and crafts include increasing the student's interest in handmade work and inspiring inventive and experimental crafts while helping the student to visualize and master the en-

[3] The text refers to the researched school's curriculum. The name of the school has been anonymized.

tire crafting process and its documentation. The students are also guided to identify the conceptualizations and to know and work on a wide variety of materials as well as instructed in the use of ICT in the design, production and documentation of the craft process. (Local curriculum document, 2016[4].)

## 5.3 The FUSE Studio as a learning environment

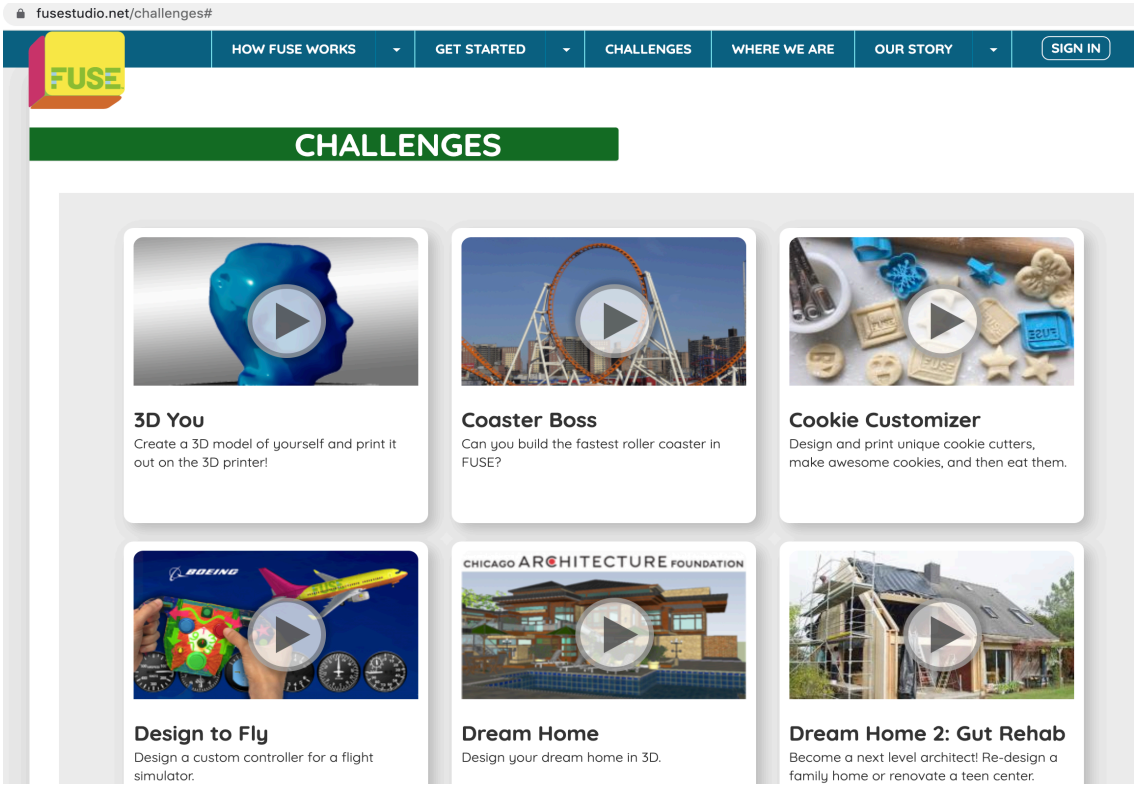
The FUSE Studio is a learning environment that consists of (at the time of data collection) 24 STEAM (science, technology, engineering, arts, mathematics) related design and making challenges, that have a levelling-up structure of video games. The student progresses from one level to another by demonstrating completion of the task by uploading a digital artifact, often a picture or a video, to the FUSE platform. The tasks get harder level by level and require the students to use skills learned in the prior levels. (Hilppö & Stevens, 2020.)

The FUSE Studio platform includes the instructions and support material for the challenges (for example, see picture 1). Some of the challenges, like *Dream Home*, are performed on a computer, either on the FUSE platform or using additional software. Others, such as *Spaghetti Structures* and *Solar Roller*, are worked on using physical tools, such as spaghetti and marshmallows, and solar panels and capacitors. There are also challenges that combine the digital and the physical elements. For example, in *Jewelry Designer*, both physical tools (pen and paper to visualize the size) and software (for designing a 3D rendering of the jewelry) are used.

The FUSE Studio was developed in collaboration with teachers and researchers. The challenges integrate student interests to STEAM with the aim of developing students' 21st century skills, such as critical thinking, collaboration skills and creativity. In the FUSE Studio, emphasis is put on students' agency, by allowing them to choose the challenge, pace and the group they want to work with and by

[4] The text refers to the researched school's curriculum. The name of the school has been anonymized.

encouraging students to use their growing expertise and share their knowledge with each other. The teachers act as facilitators that complement the instructions and tutorials found in the FUSE website. Another key principle in the FUSE Studio model, is learning from failure. Since there aren't traditional consequences of failure, like bad grades, the students accept failure as "just another try". (Hilppö & Stevens, 2020.)




Picture 1. FUSE Studio home view.

# 6 Research methods

In this chapter, I introduce the qualitative research strategy of this study by describing the data collection and the process of data analysis.

## 6.1 Data sources

This master's thesis utilizes research data that belongs to a research project ”Learning by Making: The Educational Potential of School-based Makerspaces for Young Learners' Digital Competencies” (iMake, project no: 310790), funded by the Academy of Finland and led by Professor Kristiina Kumpulainen. I was not involved in the data collection or research group myself, but I was able to use their data to conduct this research.

The data consisted of 75 hours of video recordings and was collected in the fall of 2016. A total of 94 students from grade levels 4.-6. and their facilitator-teachers attended the FUSE Studio sessions. In the 4th grade group there were 32 students (22 boys and 10 girls), 30 students (19 boys and 11 girls) in the 5th grade group and in the 6th grade group 32 students (19 boys and 13 girls). Three groups of students and teachers were filmed at three FUSE sessions per week by using two to four cameras simultaneously. Half of the cameras were focused on filming on students working while the other half was filming the teachers. At least one teacher was being followed and filmed by a researcher on each session. The cameras that were focused on filming an individual or a group of students were not generally moved but were meant to caption all the work that took place on the session. Student cameras were placed to include the equipment and computer screens used by students whenever it was possible and/or seen as an important part of the problem solving or interactions. Both teachers and student's speech were recorded by using wireless microphones that were linked to the video cameras.

The focus of this study was to find out what kind of expressions of transformative agency could be found in students' work in the FUSE Studio learning environment. The findings of the first research question revealed that episodes, in which the tools mediated the emergence of transformative agency, were found in all six types of transformative agency according to the classification of Haapasaari and colleagues (2016). This led to the second research question being asked: what kind of roles do tools play in the emergence of students' transformative agency in the FUSE Studio?

I included in the analysis episodes describing the activities of students working alone and in small groups, provided that the episode could be analyzed and the expressions of students' transformative agency concluded by primarily focusing on verbal interaction. This interaction could take place both between students and also between students and teachers. Episodes in which an individual or a group of students worked silently were not included in the analysis.

## 6.2 Methods of data analysis

I initially watched the entire video footage that had been filmed from the beginning of September to the end of November 2016. It consisted of 177 video clips. Of these clips, I ignored the 26 that were clearly accidental recordings, i.e., the camera was filming a wall, or the clip was only a few seconds long. I also ignored video clips that contained, for example, a discussion between teachers or between teachers and researchers. Finally, I analyzed 126 video clips, totaling 72 hours in length, that included student work. Sometimes the video was interrupted, so the video depicting the same session was split into several clips. The videos analyzed, are compiled in Appendix 2, where they are reported so that clips depicting the same students or teachers are combined into complete videos. Hence, there were 97 complete videos.

I began the analysis by familiarizing myself with the content log of the video corpus composed by a member of the research group. The content log included the date and time, name, camera number, the focus of the camera and the challenge/

main events of the clip. I used the content log as a basis, to which I recorded my analysis, for this study (see Appendix 2 for the applied version). I then proceeded with the analysis in iterative phases combining data and theory (see e.g. Srivastava & Hopwood, 2009). Derry and colleagues (2010) advice, that using theoretically motivated orienting questions help not losing perspective due to the numerous details contained in the extensive video material (Derry et al. 2010, 16).

This study follows the six types of transformative agency identified by Haapasaari and colleagues (2016), namely *Resisting* and *criticizing* indicate the wish to change the activity, *explicating new possibilities or potentials in the activity* brings up new potentials of the problematic object, *envisioning new patterns of models of the activity* refers to suggestions or plans to change the current activity, *committing to concrete actions aimed at changing the activity* is usually expressed with commissive speech and finally, *taking consequential actions to change the activity*. According to Haapasaari and colleagues (2016), “agency is expressed in discourse and action” (Haapasaari et al., 2016, 240). The episodes I selected for analysis in this study, had to primarily contain a verbal expression, by which the expression of transformative agency appeared. In some situations, students clearly demonstrated transformative agency through action, I also included such episodes in the analysis. I did not limit the actors selected for the analysis, so I included situations where students worked alone and those where students worked in groups or in collaboration with a teacher.

According to Alasuutari (2011), reduction of observations takes place in two phases. First, when looking at the material, only issues that are relevant to a particular theoretical framework and research questions are considered. In this way, the material can be reduced to a more manageable number of “raw observations”. In the second phase, the raw observations are combined into one of few observations by searching for a common feature and formulating a rule that applies to the entire material. (Alasuutari, 2011, 32.) In the first phase of the analysis, I sampled the videos to get an overview of the material. I made preliminary classifications before I decided to approach the video corpus using the framework

of types of transformative agency identified by Haapasaari and colleagues (2016). Although my analysis was based on a guiding theory, I sought to proceed in a data-driven manner so that the multidimensionality of students' transformative agency could be seen in the features of the types of transformative agency I identified. I proceeded the analysis from the examination of the whole material (75h) to the selection of individual episodes (Derry et al., 2010), according to the first research question: what types of expressions of transformative agency are found in students' work in the FUSE Studio.

I recorded and tabulated the episodes showing expressions of students' transformative agency that appeared in the material and combined them with the classification of Haapasaari and colleagues (2016). I found a total of 136 expressions describing students' transformative agency. According to Cohen, Manion and Morrison (2007), with constant comparison, existing data and theories are compared to newly acquired data (Cohen, Manion & Morrison, 2007). During the analysis, I searched for key features of student activity within the types of transformative agency and formed a description of the features of students' transformative agency in this study. Table 1 describes the features of the types of transformative agency found in this study in connection to the types of transformative agency according to Haapasaari and colleagues (2016).

Table 1. Expressions of students' transformative agency.

| Types of transformative agency | Features of the types of transformative agency in this study | Expressions of transformative agency |
|---|---|---|
| **Resisting:**<br>**this may take the shape of criticism, questioning, opposition or rejection.** | Opposing initiatives to transform the activity. Refusing to work or acting in a disruptive way. | "*No tunnel ...*"<br>Students are working on the Coaster Boss challenge and one of them proposes that they should build a tunnel. |
| **Criticizing:**<br>**criticizing the current activity. Change oriented and aiming at identifying problems in current ways of working.** | Showing uncertainty, playing and tinkering with tools, fooling around, opposing current activities. | "This would make a great reading light …"<br>Two students are working on Electric Apparel, with one of the girls focusing on playing with LED lights instead. |
| **Explicating new possibilities or potentials in the activity:**<br>**relating to past positive experiences or former well-tried practices.** | Extending the given instructions by planning and explicating creative acts or use of tools in an unexpected way. | *"But could they be like this [draws] let's imagine this is a star and this is the moon."* A group of girls are working on the Jewelry Designer and and design more complex jewelry than requested in the instructions. |
| **Envisioning new patterns or models of the activity:**<br>**future oriented suggestions of a new way of working.** | Planning to deviate from instructions in pursuit of the students' own interests. | *"But do I have to make earrings?"*<br>A student doesn't want to design earrings as instructed in the *Jewelry Designer* challenge, so with a teacher and another student they come up with a different plan. |
| **Committing to concrete actions:**<br>**committing to taking concrete, new actions, typically manifested in the use of commissive speech acts.** | Committing to materializing ideas into alternative solutions. | *"Um ... I'm going to ask for the tape."* Students are working on the Coaster Boss challenge and start building tunnels. |
| **Taking consequential actions to change the activity:**<br>**reporting having taken consequential actions to change the activity.** | Creating an alternative design and making activity that meets the students' interests. | "As far as I remember, the challenge was you were supposed to use a certain amount of spaghetti and a certain number of marshmallows and you have used ..."<br>Two boys are building large constructions of marshmallows and spaghetti. |

The emergence of transformative agency is a cyclic and non-linear process (Kajamaa & Kumpulainen, 2019), so in one episode several expressions of students' transformative agency could be seen. I classified the episodes according to which type was most prevalent in that episode. In the findings chapter, I present examples to illustrate the expressions of the emergence of students' transformative agency that I identified from the data. I first transcribed the examples in Finnish and then translated them idiomatically into English.

I noticed that episodes in which I identified expressions of transformative agency in students' actions, were often related to FUSE challenges that used physical tools. Based on this observation, I formulated the second research question: what kind of roles do physical tools play in the emergence of students' transformative agency in the FUSE Studio? I continued the analysis by sampling the 136 episodes in which I identified expressions of students' transformative agency, and re-watched videos of each type, from the perspective of the second research question. I combined the types of transformative agency into three stages of emergence of students' transformative agency and sought to describe the central role of the tools in relation to each. I found the tools to arouse curiosity and playfulness, and that this was particularly related to resisting and criticizing. Then, tools inspired imagination of new possibilities, that was especially related to explicating new possibilities or potentials in the activity and envisioning new patterns or models of the activity. Finally, the tools acted as facilitators of students' alternative design and making activities, that I connected to committing concrete actions and taking consequential actions to change the activity. In the findings chapter, I present the roles I identified with examples transcribed from the data.

# 7 Findings

In this chapter, I will present the results of this study. I report the findings in the order of the research questions. First, I answer the first research question by classifying and describing the manifestations of students' transformative agency found in the data and connecting them to the types of transformative agency identified by Haapasaari and colleagues (2016). Then, I describe the roles that the physical tools used in the FUSE Studio played in the emergence of students' transformative agency. I illustrate the interpretations I have made with examples that I have transcribed from the video data. The examples are presented in both Finnish and English. The names of students and teachers have been changed to ensure anonymity.

## 7.1 Types of expressions of transformative agency found in students' work in the FUSE Studio

Next, I will present the types of transformative agency and their features in this study through examples that illustrate the expressions of transformative agency (see Table 1). I will then present the findings of the second research question, what kind of role did physical tools play in the emergence of students' transformative agency in the FUSE Studio, by connecting the types of expressions of student's transformative agency found in the first research question to descriptions of tool use. The roles the tools played in mediating the emergence of transformative agency are called tools arousing curiosity and playfulness, tools inspiring imagination of new possibilities and the tools as facilitators of students' alternative design and making activities.

### 7.1.1 Resisting

Resisting appeared in this study as students opposing initiatives to transform the activity, refusing to work or acting in a disruptive way. When working in groups or in pairs, a student could suggest deviating from the instructions and other students may not have been willing to do so. Sometimes, a student refused to work

and thus expressed rejection or questioning of the teacher's instructions and/ or the FUSE Studio. Disruptive behavior, involving one or more students, interfered with the work of other members of the group. In these episodes, opposition was directed at disruptive students.

In the following example, three boys are working on the *Coaster Boss* challenge. In the challenge, students must build a roller coaster of a certain length along which a marble ball can pass, using foam strips. There must be one loop on the track and the ball must reach a certain speed. Two of the students are more involved and one is alternating between working and fooling around. They have finished the track and checked the marble's speed. During the session other students come and go, some participating in the building of the track, others just watching.

**Example 1.**

| | |
|---|---|
| Student 1/Nathan: "But we don't need the straight piece. This is all done."<br>Student 2/Samuel: "A Tunnel! [Sets the track as an extension of an existing track.] Ha, ha, ha, ha, ha…."<br>S1/ Nathan: "No tunnel ..."<br>S2/Samuel: "Why?<br>S1/Nathan: "Because… [The end is inaudible.] | Oppilas 1/Nathan: "Mut ei me tarvita suoraa. Tää on niinku valmis."<br>Oppilas 2/Samuel: "Tunneli! [Asettelee radanpalaa olemassa olevan radan jatkeeksi.] Ha, ha, ha, ha, haa…"<br>O1/Nathan: "Ei tunnelia…"<br>O2/Samuel: "Miks?<br>O1/Nathan: "Noku… [Lopusta ei saa selvää.] |

In the beginning of the episode, Nathan states that the track is ready and doesn't need any more parts in it. Samuel excitedly proposes a tunnel that Nathan declines. In this example, Nathan resists Samuel's initiative to modify the track's design by building tunnels.

### 7.1.2 Criticizing

Criticizing appeared in this study as students showing uncertainty, playing and tinkering with tools, fooling around and opposing current activities. On some oc-

casions, playing with the tools could be interpreted to hide the fact that the students either didn't understand the instructions or the objectives of the challenge or that they simply weren't that motivated to work with it. In addition, tinkering with the tools or software was a way to get familiar with the challenge and the equipment, for the student/s to see how things work before diving into the challenge itself.

In the following example, two girls are working on the *Electric Apparel* challenge. The goal of the challenge is to design a small piece of clothing that is connected to little LED lights. Anna is focused on designing gloves that light up, while Bea is tinkering with the LEDs. Bea's actions can be understood as criticizing the current situation and seeking to change it by playing with the LEDs. Anna, in turn, can be seen resisting Bea's attempts to get Anna to play with her.

**Example 2.**

| | |
|---|---|
| Student 1/Anna: "I would do that… Bea! Do you have to do it all the time… [Gives a laugh.] | Oppilas 1/Anna: "Mä tekisin sillee… Bea! Onks sun ihan pakko tehä tota koko ajan…" [Naurahtaa.] |
| Student 2/Bea: "Yes…" [Inaudible for transcription.] | Oppilas 2/Bea: "On…" [Ei saa selvää.] |
| S1/Anna: "Would it be nice Bea, or… In your opinion…" | O1/Anna: "Oisko semmonen Bea kiva, tai… Sun mielestä…" |
| [Bea still tinkers with the lights.] | [Bea näprää edelleen valoja.] |
| S1/Anna: "Okay Bea… [Both laugh] So would it be… Which one do you think…" | O1/Anna: "Okei Bea… [Molemmat naurahtavat] Nii oisko se… Kumpi ois sun mielest…" |
| S2/Bea: "This would make a great reading light …" | O2/Bea: "Täst sais hienon lukuvalon…" |
| S1/Anna: "They come right into my eyes those lights!" [Puts her hand in front of her eyes.] | O1/Anna: "Ne tulee suoraan mun silmiin ne valot!" [Laittaa käden silmiensä eteen.] |
| [Bea's construction falls on the table and breaks, the students continue the conversation about battery placement.] | [Bean rakennelma tipahtaa pöydälle ja hajoaa, oppilaat jatkavat yhdessä keskustelua pariston sijoittamisesta.] |
| S2/Bea: "Could there be a little snap fastener here?" | O2/Bea: "Voisko siin olla semmonen pieni neppari?" |
| S1/Anna: "Sure." | O1/Anna: "Vaikka." |
| S2/Bea: "And that's how it goes off and on?" | O2/Bea: "Ja siit se niinku sulkeutuu ja menee päälle?" |
| S1/Anna: "No…" [Shakes her head.] | O1/Anna: "Eeeiii…" [Pudistelee päätään.] |
| | O2/Bea: "Joojoo, se olis hieno. Okei toi oli tosi outoo varmaan." |

S2/Bea: “Yeah yeah, that would be great. Okay that must have been really weird.”

[Anna continues to ponder the location of the battery, Bea begins to tinker with the supplies.]
S1/Anna: “Okay Bea, you should design it now.”
S2/Bea: “Yeah I'm designing it at my reading light.”
[Students continue to plan the design and functionality of the gloves. Anna is leading the activity by vocalizing the plans out loud. Bea makes a suggestion to which Anna replies by turning down the idea.]

S2/Bea: “Okay… [Turns to her paper and almost immediately back to Anna.] So we’re not really doing anything on this session or…”

[Anna does not answer but continues to plan out loud. In a moment, Bea joins the conversation.After a few minutes, Bea starts a discussion about the colors of the led lights and continues tinkering with the lights and the battery. Anna tries to redirect the conversation back to the functionality of the gloves.]

S1/Anna: “Well, if you have them like that… Are they like that Bea that you have them like next to the battery that they all light up at once or…”
S2/Bea: “I don't know ... I'm not quite sure.” [Twiddles battery and lights combination in her hands.]
S1/Anna: “They come right into my eyes Bea… And now there’s a good thing that if you have a snap fastener, you can put that snap on and…”
S2/Bea: “Laser…” [Pointing at her hands and desk, continuing to tweak the lights, does not seem to pay any attention to what Anna says.]

[Anna jatkaa pariston sijainnin pohtimista, Bea alkaa näpertää tarvikkeilla.]
O1/Anna: “Okei Bea, sun pitäis nyt suunnitella sitä.”
O2/Bea: “Joo mä suunnittelen sitä mun lukuvaloni ääressä.”

[Oppilaat jatkavat käsineiden ulkonäön ja toiminnallisuuden suunnittelua. Anna johtaa toimintaa sanoittamalla suunnitelmiaan. Bea tekee ehdotuksen, mihin Anna vastaa hylkäämällä idean.]

O2/Bea: “Okei… [Kääntyy paperinsa puoleen ja melkein heti takaisin Annaan päin.] Eiks me ees tehä täl tunnil niinku viel oikeen mitään tai…”

[Anna ei vastaa vaan jatkaa suunnittelua ääneen. Hetken päästä Bea yhtyy keskusteluun. Muutaman minuutin päästä Bea aloittaa keskustelun led valojen väreistä ja jatkaa valojen ja pariston kanssa näpertämistä. Anna yrittää ohjata keskustelun takaisin käsineiden toiminnallisuuteen.]

O1/Anna: “Jaa jos sul on tollain… onks ne sillain Bea et sul on niinku siin patterin vieressä et ne kaikki syttyy kerralla vai…”
O2/Bea: “En mä tiedä… Mä en oo oikeen ihan varma.” [Pyörittelee paristojen ja valojen yhdistelmää käsissään.]
O1/Anna: “Ne tulee suoraan mun silmiin Bea… Ja nyt täs on se hyvä juttu et jos siin on neppari, ni sen nepparin voi laittaa kiinni ja…”
O2/Bea: “Laaseri…” [Osoittelee valoilla käteensä ja pöytään, jatkaa valojen näpertämistä, ei vaikuta kiinnittävän Annan puheisiin liiemmin huomiota.]
O1/Anna: “Hehehee… [Väkinäinen naurahdus.] Nyt se osottaa uudestaan mua silmiin, nii Bea, et jos siin on neppari, ni ne pysyy siinä eikä tarvii pitää tällein kiinni

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| S1/Anna: “Hehehee ... [Forced laughter.] Now it points my eyes again, so Bea, that if there is a snap, it stays there, and you don’t have to have to hold on to it like this. [Thumb pressed inside of palm.] When there are those [sighs] those that… well I’ll show with this.” [Turns the computer screen.]<br>S2/Bea: “Well now I have the reading light again.” [Turns to look at Anna's computer screen.] | [painaa peukalolla kämmenen sisäpuolta] ku on semmosii [huokaus] semmosii että… no mä näytän tällä.” [Kääntää tietokoneen näyttöä.]<br>O2/Bea: Nonii nyt mul on taas lukuvalo. [Kääntyy katsomaan Annan kääntämää tietokoneen näyttöä.] |

Bea doesn’t seem to think designing (as instructed) is “doing anything”, so she criticizes the current activity by focusing on more interesting activities, that is, playing with the LEDs. There are some hints in the excerpt, that might suggest that Bea might not be quite confident in her abilities or understanding of the challenge, and that she might try to hide that in tinkering. This view could be supported by Bea’s reactions (returning to tinkering, invalidating her own comment by saying it is weird) to situations where Anna turns her suggestions down. Later recordings show Anna working on the challenge over several sessions and eventually getting the gloves ready. Bea isn’t seen on working with the challenge on later recordings.

### 7.1.3 Explicating new possibilities or potentials in the activity

Explicating new possibilities or potentials in the activity appeared in this study as students extending the given instructions by planning and explicating creative acts or use of tools in an unexpected way. Students extended the given instructions by envisioning designs or acts by discussing, outlining or asking for permission or a teacher’s opinion. Proposing and explaining new possibilities was quite common in the data but not all situations led to a change in activities.

In the following example, four girls are working on the *Jewelry Designer* challenge. The level one’s objective is to create a 2D-design of a pair of earrings using basic shapes. They discuss with the teacher whether stars or initials could be considered as basic enough shapes to be used in the design.

**Example 3.**

Student 1/Emma: “Could it be a star and a moon?”
Student 2/Lisa: “In earrings.”
S1/Emma: “Or does it have to be a square? Like a crescent moon thing?”
S2/Lisa: “Could it be initials?”
Teacher Jim: “So what are you doing?”
S2/Lisa: “Umm…”
S1/Emma: [Exclaims.] “Oh earrings!”
Student 3/Katy: “Earrings with the 3D-printer.”
T J: “Okay, and what are you supposed to do in that challenge? Tell me a little about that.”
S2/Lisa: “Make… earrings.”
S3/Katy: “Which would be the right size.”
S1/Emma: “And they should weigh only five grams.”
T J: “Weigh five grams.”
S1/Emma: “But could they be like this [draws] let’s imagine this is a star and this is the moon.”
T J: “So are there any instructions on that they should be some specific shape?”
S1/Emma: “It said to use basic shapes.”
S3/Katy: “So it shouldn't be anything like you wouldn't do something like this... [Waves the pen in the air.]
S2/Lisa: “Could it be an initial?” [Rest is inaudible.]
S1/Emma: “But could it print like a moon and a star? [Draws.] I mean star… I mean… I mean…”
T J: “Mmm… [Inaudible.] Either or… Yes, I would think that those…”
S1/Emma: “So that this would have a moon and this a star.” [Points at her ears clarifying that she wants a moon for one and a star for the other ear.]
T J: “Mmm. So well, they have to be drawn separately then. [Rest is inaudible.]
S2/Lisa: [Giggles.]

Oppilas 1/Emma: “Voiks olla tähti ja kuu?”
Oppilas 2/Lisa: “Korviksissa.”
O1/Emma: “Vai pitääkö olla neliö? Sellanen kuunsirppiasia?”
O2/Lisa: “Voiks olla nimikirjaimet?”
Opettaja Jim: “Ai mitä te teette?”
O2/Lisa: “Ööö…”
O1/Emma: [Huudahtaa.] “Aah korviksii!”
Student 3/Katy: “Korviksii sil 3D-tulostimella.”
O J: “Okei ja mitä teiän haastees pitää tehdä? Kertokaa mulle vähän siitä.”
O2/Lisa: “Tehä… korvikset.”
O3/Katy: “Jotka olis oikeen kokoset.”
O1/Emma: “Ja viis grammaa vaan painaa.”
O J: “Viis grammaa painaa.”
S1/Emma: “Mut voiks ne olla vaik tälläset [piirtää] leikitää et tää ois tähti ja sitte täs ois tää kuu.”
O J: “Nii onks siinä annettu teille jotku ohjeet et pitää olla jonkun tietyn muotoset?”
S1/Emma: “Siin sanottii et perusmuotoja.”
S3/Katy: “Et se ei sais olla mitää esimerkiks et menis jotain tälläsii... [Heiluttaa kynää ilmassa.]
S2/Lisa: “Voiks olla nimikirjain?” [Loppua ei kuulu.]
S1/Emma: “Mut pystyyköhän se tulostaa niinku kuun ja tähden? [Piirtää.] Eiku tähden… eiku..eiku…”
O J: “Mmm… [Ei saa selvää.] Jommankumman… Kyl mä niinku näkisin että noi…”
O1/Emma: “Mut siis sillain niinku et täs olis kuu ja täs olis tähti.” [Osoittaa korviaan selventäen, että haluaa toiseen korvaan kuun ja toiseen tähden.]
O J: “Mmm. Nii no erikseen ne pitää piirtää sitten.” [Loppua ei kuulu.]
O2/Lisa: [Naurahtaa.]
O J: “Joo… tota… [Lopusta ei saa selvää, kumartuu Emman läppärin luokse.]
O2/Lisa: “Se on enkuks nii siks meil on vaikeeta.”
O J: “Joo ei mitään.”

T J: “Yeah… sure …” [Rest is inaudible, bends over to the Emmas laptop.]
S2/Lisa: “It’s in English, that’s why we’re struggling.”
T J: “Yeah, it’s nothing.”
[Lisa and Katy start drawing, teacher looks for instructions.]
S1/Emma: “Do you know what is supposed to…” [Rest is inaudible.]
T: Well, the first instruction, as such, is to think first in this first phase as simple as possible. So I suppose that like making of umm more complex, question marks or initials, making probably is possible at some point but first think about just if it were like it or like it says here like…” [Rest is inaudible.]
S3/Katy: “But if the star would be…” [Inaudible.]
T: [Continues explaining the instructions.] “...just using basic shapes... for this first one.”
S3/Katy: “If the star… [inaudible.] Was like that kind and not like this kind [draws a star in the air] so is it then like…”
T J: “Well you should to give it a try. I don’t think you should think too much about how hard it is but to start trying instead and if it starts to feel like okay, this isn’t going to work then at that point change the plan.”
S2/Lisa: “Okay, I’m gonna make many alternatives.”
T J: “That is also an option but decide now what you are going to do because it is not worth having it start doing the 3D design in a way that okay I’m going to try little bit of everything but that you choose the one that you’re really going to make and then if it turns out it won’t work then change the plan after that.”

[The teacher leaves, the girls focus on drawing.]

[Lisa ja Katy alkavat piirtämään, opettaja katsoo ohjeita.]
O1/Emma: “Tiedätsä mitä niis piti…” [Lopusta ei saa selvää.]
O J: “No tos niinku täs ensimmäinen ohjehan tietysti oli varsinaisesti et miettikää aluks täs ensimmäisessä vaiheessa mahdollisimman yksinkertainen. Eli mää uskon, että tuota et et niinku se monimutkasemmankin ää tekeminen kysymysmerkkien tai nimikirjainten tekeminenkin varmaan sit niinku jossain vaihees onnistuu mut miettikää aluksi ihan vaan vaikka se se niinku ois tai niinku tos sanotaan niinku…” [Lopusta ei saa selvää.]
O3/Katy: “Mut jos se tähti ois esim…” [Ei saa selvää.]
O J: [Jatkaa ohjeiden selittämistä.] … ihan perusmuotoja… hyödyntäen nyt tää ensimmäinen.”
O3/Katy: “Jos se tähti... [Ei kuulu.] Ois sillain tollanen et se ei ois sellanen tällänen [piirtää tähden ilmaan] nii onks se sillon niinku…”
O J: “No sitähän täytyy lähtee koittamaan. Emmä tiedä kannattaaks täs vaihees miettiä liikaa sitten, että niinku et onks se vaikee vaa lähtee koittamaan ja sit jos alkaa tuntuu, että okei tää ei onnistu nii sit muuttaa suunnitelmaa.”
O2/Lisa: “Okei, mä teen monta vaihtoehtoo:”
O J: “Seki on yks vaihtoehto mut että päättäkää nyt joku mitä lähette tekemään koska ei kannata ottaa sitä lähtee tekemään sitä 3D -suunnittelua sillee et oke mä kokeilen vähän kaikkea vaan sit valitsee niistä sen mitä lähtee oikeesti tekemään ja sit jos osottautuu et se ei onnistu nii sit vaihtaa suunnitelmaa sen jälkeen.”

[Opettaja poistuu paikalta, tytöt keskittyvät piirtämiseen.]

In this example, students enthusiastically consider different options for materializing their design. They review the instructions with the teacher but still stick to their plan to design more complex earrings.

### 7.1.4 Envisioning new patterns or models of the activity

Envisioning new patterns or models of the activity appeared in this study as students planning to deviate from instructions in pursuit of the students' own interests. Among other things, students planned to use another group's video to get directly to the next level in the challenge, were interested in the reflections they produced when pointing a laser at the camera lens and planned to repair the headphone jack on a student's phone.

In the following example, a student is starting to work on the *Jewelry Designer* challenge and explaining how he's going to design a wristband. As the teacher translates the instructions, he learns that he should design earrings. The student seems reluctant to design the earrings, so together with the teacher and another student, they come up with an idea for a finger jewelry.

**Example 4.**

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| Student 1/ Evan: "But do I have to make earrings?" | Oppilas 1/Evan: "Mut onks pakko tehä korvakorut?" |
| Teacher Annie: "Umm well so that you can get to the next level so you should… but wait you can, they don't necessarily have to be… what else could they be if not earrings?" | Opettaja Annie: "Aaa no siis niinku et jotta sä pääset seuraavalle tasolle ni sun pitäis tää… mut sä voit oota no ei ne välttämättä tarvii olla… mikähän muu ne vois olla jos ne ei oo korvikset? |
| Student 2/ Barney: "A finger jewel." | Oppilas 2/Barney: "Sormikoru." |
| T A: "For example, sure. Did you hear that?" | Opettaja Annie: "Nii, esimerkiks. Kuulitko?" |
| S1/Evan: "Yeah." | O1/Evan: "Joo-o." |
| T A: "Mmm. Because that's about the same size." | O A: "Mmm. Koska se on about niinku samaa kokoo." |
| S1/Evan: "Mmm." | O1/Evan: "Mmm." |
| T A: "As an earring. So, the idea with that is, that you take the measurements." | O A: "Kun korvis. Nii siin on idean se et siin otetaan niinku ne mitat." |
| S1/Evan: "Yhmh." | O1/Evan: "Yhmh." |

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| T A: “Yes because after that you make like a digital modeling of that. But the finger… fingerjewelthingy… it probably works just the same as an earring.” | O A: “Joo koska sen jälkeen sä teet siitä niinku digitaalisen mallinnoksen. Mut sormi... sormikorusysteemi… se varmaan toimii ihan yhtä lailla ku korvis.” |

Instead of the student following the instructions despite his reluctance, he expresses a desire to design a meaningful piece of jewelry for himself, which leads to a joint brainstorming with the teacher and another student. This evolves into a finger jewelry idea that the student begins working on.

### 7.1.5 Committing to concrete actions

Committing to concrete actions appeared as students committing to materializing ideas into alternative solutions. Students used both verbal and nonverbal, such as using tools or starting to make changes in the design, expressions for taking concrete new actions.

The following example, in which students work on the Coaster Boss challenge, continues where the example 1 used in the “resisting” type left off, that is, a situation where Samuel suggested building a tunnel, but Nathan refused. In a while, another student comes to ask if they plan to make the track longer. This time, Nathan’s answer isn’t quite as sharp, and Samuel is still insistent on refining the track’s design.

**Example 5.**

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| Student 4/Connor: "Will you, will you make this even longer?"<br>S1/Nathan: "Probably not."<br>S2/Samuel: "Yes." [Sends a ball along the path.]<br>S4/Connor: "Does it work?"<br>S2/Samuel: “It works. On level one it needs to have a loop.”<br>S1/Nathan: “Yeah and there, there, is no problem anymore. Hey look, now there is no problem that it can pull over here, which is, by the way, possible ...” [Tinkering at the end of the track.] | Oppilas 4/Connor: “Aiottekse, aiottekste tehä täst viel pidemmän?”<br>O1/Nathan: “Ei varmaankaan.”<br>O2/Samuel: “Kyllä.” [Lähettää kuulan rataa pitkin.]<br>O4/Connor: “Toimiikse?”<br>O2/Samuel: “Toimii. Ykköstasos kuuluu olla kieppi.”<br>O1/Nathan: “Nii ja täs, täs ei oo enää mitää ongelmaa. Hei kato, nytten täs ei oo ongelma, että se voi kato tässä kohti vetää tällein yli, joka on muuten mahdollista…” [Näpertää radan loppua.] |

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| S2/Samuel: [Clapping his hands together.] "Let's make tunnels, like these little tunnels along the way." [Takes hold of small tracks.]<br>S1/Nathan: "Let's make it at the end."<br>S2/Samuel: "And one here!" | O2/Samuel: [Taputtaa käsiään yhteen.] "Tehään tunneleita, vaikka tämmösii pikkutunneileita matkan varrelle." [Ottaa käteensä pieniä radanpätkiä.]<br>O1/Nathan: "Tehään se tähän loppuun."<br>O2/Samuel: "Ja yks tähän!" |

Connor asks if Samuel and Nathan are planning to make the track longer, to which Samuel replies with certainty, "Yes". After Samuel tells Connor, that the track works and demonstrates this with sending the marble through it, Nathan gets a little enthusiastic and starts to envision a new design for the track. Samuel gets excited about this and proposes to build the tunnels again. This time Nathan agrees by saying, "Let's make it at the end". They begin to outline a new design.

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| S2/Samuel: "I know how to make this really nice!"<br>Student 5/Max: "Can I join this? Can I join?"<br>S2/Samuel: "Do you have anything else to do?"<br>S5/Max: "No."<br>S2/Samuel: "Okay. I don't know but this is..." [The end is inaudible.]<br>S5/Max: "Why don't you add, why don't we add something to it? [Moves closer. Nathan and Tyler leave. Samuel is thinking and waving a piece of the track.] I'm thinking something like this…" [Reaches out to take a piece of the track from Samuel.]<br>S2/Samuel: "A Tunnel!" [Holds a track piece and looks at Max enthusiastically.]<br>S5/Max: [Enthusiastically] "Well, why not! Look, if you put this... [Installs a piece of track as a continuation of the previous track.] Or look, think about, we would put this here, or some other thing, it would turn around... it would go so high because it would get quite a bit of speed like it would go from there and then we would put this one straight and it would go from there to like a tunnel. [Gestures with his hands.] Or | O2/Samuel: "Mä tiedän miten me saadaan tosi hyvä!"<br>Oppilas 5/Max: "Pääsenks mä tähän mukaan? Pääsenks mä mukaan?"<br>O2/Samuel: "Onks sul mitään muuta hommaa?"<br>O5/Max: "Ei."<br>O2/Samuel: "Okei. Mä en tiedä mut tää on..." [Lopusta ei saa selvää.]<br>O5/Max: "Miks te ette lisää, miks me ei lisätä siihen jotain? [Siirtyy lähemmäs. Nathan ja Tyler poistuvat. Samuel miettii ja heiluttaa radan palaa.] Mä mietin kato tällein…" [Kurottaa ottamaan radan palaa Samuelilta.]<br>O2/Samuel: "Tunneli!" [Pitää radan palasta kiinni ja katsoo Maxia innostuneesti.]<br>O5/Max: [Innostuneesti] "No, vaikka! Kato, jos sä laitat tän… [Asentaa radan palan aiemman radan jatkoksi.] Tai kato, mieti kato, me laitettais tällei tää, tai joku muu juttu, sit se kääntyis… se lähtis niinku näin korkeemmalle, koska se sais tuolta aikamoiset vauhdit, sit se niinku sieltä kiertäis ja sit me laitettais tähän sellanen suora ja sit se menis sieltä niinku tunneliin. [Elehtii käsillään.] Tai no se käännös |

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| that turn would be a bit difficult like this. [Adjusts a track piece. Samuel chuckles.] Or just put the tunnel. Tape."<br>S2/Samuel: "Um ... I'm going to ask for the tape." | olis vähän vaikee tälleen. [Asettelee palaa. Samuel naurahtaa.] Tai sit laittais vaan tunnelin. Teippaa."<br>O2/Samuel: "Öööö… Mä käyn kysyy teippii." |

In a while, Max, who has been working on another challenge in the same hallway, asks if he can join in. From time to time, Max has been watching the group's work and seems to be just as interested as Samuel in building their own kind of track. Max and Samuel start to explain their visions to each other. The episode ends with Samuel's announcement that he is going to pick up the tape, expressing his commitment to concrete actions to change the activity.

### 7.1.6 Taking consequential actions to change the activity

Taking consequential actions to change the activity appeared in this study as students creating an alternative design and making activity that met the students' interests. Sometimes, the students' actions weren't focused on working with the challenge itself but rather pursuing their own interests to which the challenge acted as a framework. In some episodes, the students had already met the goals of the challenge and then decided to work further with the design of their production.

In the following example, two boys are working on the *Spaghetti Structure* challenge. They seem to be very focused on their work. In the challenge one is supposed to use a specific number of marshmallows and spaghetti to create as tall of a structure as they can, that can still hold a large marshmallow at the top. The boys have checked the instructions at the teacher's request.

**Example 6.**

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| Teacher Annie: "What was the goal here?"<br>Student 1/Alvin: "Build a big one."<br>Student 2/Felix: "The big marshmallow goes on top." | Opettaja Annie: "Mikä teillä oli niinku tää tavote tässä?"<br>Oppilas 1/Alvin: "Rakentaa iso."<br>Oppilas 2/Felix: "Toi iso vaahtokarkki tonne päälle." |

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|---|---|
| Teacher Jim: "But what was the challenge?"<br>Both students: "To get the big marshmallow on top."<br>S2/Felix: "So it stays there."<br>T J: "Yeah but what was the assignment?"<br>[The boys answer something, inaudible.]<br>Teacher Elliott: "As far as I remember, the challenge was you were supposed to use a certain amount of spaghetti and a certain number of marshmallows and you have used ..."<br>T J: "And here's the time."<br>T E: "And then in a certain timeframe."<br>S2/Felix: "It didn't say there..."<br>T E: "There is the timer that is turned on."<br>S1/Alvin: "It didn't say anything about ..."<br>T E: "Let's check it in a moment, what it says. So now you start cleaning up. Now you use everyone's spaghetti and everyone's marshmallows at once. Others can't do the challenge." | Opettaja Jim: "Mut mikä se haaste oli?"<br>Molemmat oppilaat: "Saada iso vaahtokarkki päälle."<br>O2/Felix: "Et se pysyy siinä."<br>O J: "Joo mut mikä se oli se tehtävänanto siinä?"<br>[Pojat vastaavat jotain, ei saa selvää.]<br>Opettaja Elliott: "Muistaakseni se haaste oli silleen et piti käyttää tietty määrä spagetteja ja tietty määrä vaahtokarkkeja ja te ootte käyttäny…"<br>O J: "Ja siin on aika."<br>O E: "Ja sit tietyssä ajassa vielä."<br>O2/Felix: "Siin ei lukenu…"<br>O E: "Siin on se ajastin mikä laitetaan päälle."<br>O1/Alvin: "Siin ei lukenu mitään että…"<br>O E: "Käydään kohta kattoo vaikka et mitä kaikkee siel lukee. Elikkä nytte ruvetaan siivomaan kaikkee pois. Nyt te käytätte koko porukan spagetit ja koko porukan vaahtokarkit kerralla. Muut ei pääse tekee sitä haastetta." |

In this episode, the students demonstrate transformative agency by actively changing their activities to match their own interests. The boys are not following the instructions but are intensively building large structures using a lot of material. They keep on building their own design even after a teacher checks the instructions with them and seem to be making a conscious decision to do so. In the end of the session, three teachers try to discuss with them about the goals and instructions of the challenge and tell them that they are using up the materials meant for the whole group. The boys do not allow teachers' reprimands to influence their work, but respond that there were no time or material restrictions on the challenge instructions.

## 7.2 The roles of tools in mediating students' transformative agency

The tools seemed to play an important role in awakening and enabling the students' transformative agency. I identified three types of roles for the tools. The ways the tools mediated the emergence of students' transformative agency were: tools arousing curiosity and playfulness, tools inspiring imagination of new possibilities, and tools as facilitators of students' collective output. The connection between the use of tools and the manifestations of students' transformative agency is illustrated with examples.

### 7.2.1 Tools arousing curiosity and playfulness

Tools aroused curiosity and playfulness by inspiring the students to tinker with them or to see how they could be used in other ways than instructed in the challenges. Sometimes, the tools distracted the students' work in a way that lead to disruptive behavior. In connection to resisting and criticizing, the use of tools had an important part igniting a spark in the process of emerging transformative agency.

In the following example, a girl flattens a marshmallow into a little figurine and tells her friends that she wants to write a book about "the dude" ("tyypistä").

**Example 7.**

| | |
|---|---|
| Student 1/Robin: "I made a new guy!" [Shows the marshmallow she has flattened.]<br>Student 2/ Emily: "Peter"<br>S1/Robin: "This is on an adventure… I'm going to make a book about this guy that is on an adventure."<br>S2/Emily: "At least it's easy to draw."<br>[Robin sings and plays that the marshmallow walks on the floor.] | Oppilas 1/Robin: "Mä tein uuden tyypin!" [Esittelee litistämäänsä vaahtokarkkia.]<br>Oppilas 2/ Emily: "Peter!"<br>O1/Robin: "Tää seikkailee… Mä aion tehä kirjaa tästä mun tyypistä, joka seikkailee."<br>O2/Emily: "Toi on ainaki helppo piirtää."<br>[Robin laulaa ja leikkii että vaahtokarkki kävelee lattialla.] |

The figurine ends up in the bin, but the episode is illustrates how tools can spark creative ideas, even if the action is mostly playing.

### 7.2.2 Tools inspiring imagination of new possibilities

Tools inspired imagination of new possibilities by acting as initiators for extending the instructions. On some episodes, the students wanted to modify the tools or to use tools that weren't included in the materials meant for the challenges. The tools also prompted the students to design their own challenge related artifact that did not follow the instructions. In connection to explicating new possibilities or potentials in the activity or envisioning new patterns or models of the activity, use of physical tools provided students with concrete means through which they were able to express their ideas and extend their activities beyond the instructions of the challenges.

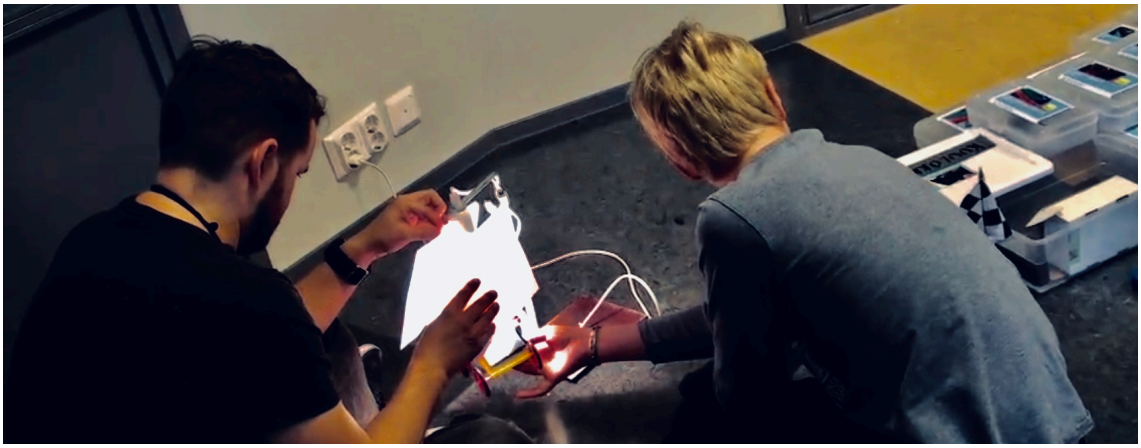
In the following example, a student and a teacher are solving a problem with the solar powered vehicle used in the *Solar Roller* challenge. The problem is that the lamps meant for this challenge need an adapter to work in the Finnish sockets, and the school doesn't have any. The original lamps have been replaced by less powerful lamps that don't produce enough energy to power the solar vehicles. Both the student and the teacher present ideas on how to extend the distance the vehicle could travel on a single charging.

**Example 8.**

| | |
|---|---|
| Student/Liam: "You have to wait a long time for the wheels to start spin." | Oppilas/Liam: "Siinä pitää odottaa todella kauan et se alkaa ees pyörii ne renkaat." |
| Teacher Jim: "Have you tried a different panel? However, there may be little difference between these panels. Hey! You know what you could try?" | Opettaja Jim: "Ooksä kokeillu eri paneelilla? Näiski saattaa olla vähä eroo näis paneeleissa. Hei! Tiedätsä mitä vois kokeilla?" |
| S/Liam: "Well?" | O/Liam: "No?" |
| T J: "White paper could help." | O J: "Valkosta paperia vähä apuna." |
| S/Liam: "How?" | O/Liam: "Miten?" |

| | |
|---|---|
| T J: “Let's take some from next to the copier… no, next to the printer some of that white paper… [Gets up and fetches paper from the class.] Let's make some reflectors out of these, because then we get a little bit more of, can increase the power if the lamp, I mean pile that light on the cell, put it there…” [Places folded pieces of paper on each side of the lamp, student puts car under the light.] | O J: “Otetaan tosta kopiokoneen vie… eiku tulostimen vierestä vähän tollast valkost paperia... [Nousee ylös ja hakee paperia luokasta.] Tehään näistä vähän heijastimia sinne, koska me saadaan näillä vähän, vähän lisää lisättyy tota tota lampun tehoa tai siis kasattua sitä valoa sinne kennolle, pistäppä se siihen…” [Asettaa taitellut paperin palat lampun molemmille puolille, oppilas laittaa auton valon alle.] |
| S/Liam: [Answer is inaudible, they let the vehicle charge for a while.] “Now that's how it should and when the capacitor is charging from here…” | O/Liam: [Vastauksesta ei saa selvää, antavat ajoneuvon latautua hetken.] “Nythän se pitää näin ja ku se kapasitaattori latautuu täält…” |
| T J: “Mmm.” | O J: “Mmm.” |
| S/Liam: “Then it should get straight through that [pointing to a tunnel made of accessory boxes] without it not hitting any wall that is impossible.” | O/Liam: “Sitten sen pitäisi saada suoraan tosta [osoittaa tarvikelaatikoista rakennettua tunnelia.] läpi ilman et se osuu, ei osu mihinkää seiniin joka on mahdotonta.” |
| T J: “Mmm.” | O J: “Mmm.” |
| S/Liam: “When does it, now that the capacitor is charged then you have to put it like this [sets the vehicle to go through the tunnel] that the capacitor… but…” | O/Liam: “Millon toi, nyt se kapasitaattori on latautunu sitte pitää laittaa se noin [asettaa ajoneuvon kulkemaan tunnelista] että se kapasitaattori… mut…” |
| T J: “Yeah but it’s not enough, not enough.” | O J: “Joo mut ei riitä, ei riitä joo.” |
| S/Liam: “Not enough. I thought maybe we could put another capacitor in it, but it doesn’t fit…” [Peeks under the panel.] | O/Liam: “Ei riitä. Mä ajattelin et siihen vois laittaa ehkä toisen kapasittaattorin mut se ei mahdu…” [Kurkistaa paneelin alle.] |
| T J: “Can't fit? Really?” | O J: “Ei mahdu? Niinkö?” |
| S/Liam: “No, it doesn’t fit.” | O/Liam: “Ei ei mahdu.” |
| T J: “Well could we put it there in a way that it fits? [They study the connections under the panel together.] Sure, we can make it fit there.” | O J: “No voisko sen laittaa sinne sillä tavalla et se mahtuu? [Tutkivat yhdessä kytkentöjä paneelin alla.] Kyllä tohon saadaan mahtumaan hyvinki.” |
| S/Liam: “Hmmm.” | O/Liam: “Hmmm.” |
| T J: “But does some friend here have another capacitor?” | O J: “Mut onks kellää kaverilla tässä vieressä toista kapasitoria?” |
| O/Liam: “I can get one.” [Leaves to find another capacitor.] | O/Liam: “Mä voin hakee.” [Lähtee etsimään toista kapasitoria.] |

In the episode, the teacher introduces an idea that a piece of white copying paper could be used to gather the light more directly to the solar panel (see Picture 2). After trying that, they find out that the charge still isn’t strong enough and the



Picture 2. Instructions were extended by using alternative tools.

student suggests adding a second capacitor. Then the student points out that there is also a problem with the design of the tunnel, that he's supposed to build for the challenge. It seems that none of the materials in the classroom, that could be used to build the tunnel, are working the way the way the student wants them to, so he suggests that maybe the challenge could be completed without actually building the tunnel.

| | |
|---|---|
| S/Liam: "Could you just put that thing on that distance without the tunnel?" | O/Liam: "Voiks vaan laittaa sen jutun sen jonkun matkan ilman tota tunnelia?" |
| T J: "Well, how's, umm, what's the point of the tunnel?" | O J: "No, mites, äää, mikähän se tunnelin niinku ajatus täs on?" |
| S/Liam: "That it would go a certain distance without light." | S/Liam: "Että se menis jonku tietyn matkan ilman valoo." |
| T J: [Nods.] Well, could you think that doing it without a tunnel, how do you make sure it doesn't get light? | O J: [Nyökkää.] "No voiskos sitä ajatella että tehdä ilman tunnelia, miten sä saat sen varmistettua et se ei saa valoa?" |
| S/Liam: "Won't use that lamp." | O/Liam: "Ei käytä tota lamppuu." |
| T J: "Does it move, does it move now in this room light?" | O J: "Liikkuuks se, liikkuks se nyt täs huoneen valaistuksessa?" |
| S/Liam: "No." | O/Liam: "Ei." |
| T J: "Mmm. So, if you want to ... now that point in the tunnel is just preventing the light from coming on so maybe you can try ... There was a certain distance, wasn't there?" | O J: "Mmm. Eli jos nyt halutaan… ku se tunnelin pointti on just se estää vaa se valon tuleminen niin ehkä sä voit koittaa… Siin oli tietty matka eiks ollukki?" |
| S/Liam: "Yeah it was a hundred meters." | O/Liam: "Joo se oli sata metrii." |
| T J: "So, measure the distance and see if it works." | O J: "Noni, mittaa mittaa se se matka ja tota kato onnistuisko se." |
| [Student stays to measure, teacher leaves.] | [Oppilas jää mittaamaan, opettaja poistuu.] |

The student completes the challenge, using two capacitors, later in the session and the teacher films the execution. This example illustrates how a situation that began as a common problem-solving evolved to extending the framework of the challenge through the use of tools.

### 7.2.3 Tools as facilitators of students' alternative design and making activities

Tools facilitated students' alternative design and making activities by enabling students to pursue their own interests. While working, the students utilized both challenge-specific tools and those found elsewhere in the school. Many of the episodes where students created an alternative design and making activity showed the change in the students' activities being inspired by the tools. By wielding track pieces, tinkering with LED lights, handling marbles and solar panels, students communicated to each other their interest to explore new possibilities and direction for their activity. In connection to committing to concrete actions and taking consequential actions to change the activity the use of physical tools helped the students to materialize their plans to change activities.

In the following example, two boys are working on the *Solar Roller* challenge, where they are supposed to assemble solar-powered vehicles and make them travel a certain distance. Alex suggests that they should race with the vehicles. With a teacher's help they plan and start a race, but they only test the first vehicle's performance when Leo remembers that they should be filming the ride.

**Example 9.**

| | |
|---|---|
| [Student 1/Alex tests the vehicle with a lamp, Student 2/Leo examines a tape measure.] | [Oppilas 1/Alex testaa ajoneuvoa lampulla, Oppilas 2/Leo tutkii mittanauhaa.] |
| S1/Alex: "Leo! Let's compete! Let's race Leo! Who…" | O1/Alex: Leo! Otetaan kilpailu! Otetaan kilpailu Leo! Kuka…" |
| Teacher Rick: "Not going to work with one lamp." | Opettaja Rick: "Ei toimi yhdellä lampulla." |
| S1/Alex: "If only we had two lamps." | O1/Alex: "Vitsit jos olis kaks lamppua." |
| T R: "Yes, I had a flashlight, but I forgot." | O R: "Niin, mulla oli taskulamppu mut mä unohdin." |

S1/Alex: “Like this ... [Places the vehicle on the floor.] I'll start though.” [Moves the checkered flag on its place.]
T R: “Well then, take the time, hey.”
S1/Alex: “So like this.”
T R: “Hey... [Alex turns to the teacher.] Take the time.”
S1/Alex: “Time, okay.”
T R: “So take the time.”
S2/Leo: “Well.” [Starts to position the tape measure and the starting point.]
S1/Alex: “Wait ... we can't we have a little... [Points at the lamp.]
T R: “Yes, you can, first you drive…”
S1/Alex: “That is too short that light. [Refers to the lamp cord.] We can't get, Leo, that far.”
T R: “But maybe from there to there. [Shows a line with a hand.] Then you can at least a meter or a meter and a half.”
S1/Alex: “One meter… aha…”
T R: “If you put it like that.” [Points a line with a hand.]
S1: “Oh yeah, let’s get a little closer Leo. [Leo tries to set tape measure.] There Leo.”
T R: “Leo and not that way. [Points.] Like that, look Leo, like that.” [Points.]
S2/Leo: “So there?”
Cameraperson: “To this wall…”
[Leo moves tape measure as shown by adults.]
T R: “Yeah, so you are like that and then… [Marks the line with hands.] You drive…”
S1/Alex: Leo watch out watch out... [Boys try to set tape measure.]
T R: “Leo, Leo… Look. Leo, Leo…”
S2/Leo: [Raises his gaze.] “What?”
T R: [Points] “Here to here … Like that, no…”
S2/Leo: “Well ... You just told to put this here.”

O1/Alex: “Tälleen… [Asettaa ajoneuvon lattialle.] Mä alotan vaikka.” [Siirtää ruutulipun paikoilleen.]
O R: “No ota sit aika hei.”
O1/Alex: “Siis tällein.”
O R: “Hei… [Alex kääntyy opettajaa kohti.] Ota aika.”
O1: “Aika, okei.”
O R: “Nii ota aika.”
O2/Leo: “Nonii.” [Alkaa asetella mittanauhaa ja lähtöpaikkaa.]
O1/Alex: “Odota… ei me pystytä meil on vähä…” [Osoittaa lamppua.]
O R: “Kyllä sä pystyt, ensin sä ajat… “
O1/Alex: “Toi on lyhyt toi valo. [Viittaa lampun johtoon.] Ei me pystytä, Leo, nii kauas.”
O R: “Mut pitäis ehkä sit tuolta tonne. [Näyttää kädellä linjan radalle.] Sit pystyy ainaki metri tai metri ja puoli.”
O1/Alex: “Metri… aha…”
O R: “Jos sä laitat sen noin.” [Osoittaa kädellään linjan.]
O1/Alex: “Ai joo mennää tohon vähän lähemmäs Leo. [Leo yrittää asettaa mittanauhaa.] Tohon Leo.”
O R: “Leo ja ei noin päin. [Osoittaa.] Noin, kato Leo noin.” [Osoittaa.]
O2/Leo: “Ai tonne?”
Kuvaaja: “Tähän seinän…”
[Leo siirtää mittanauhaa aikuisten osoittamalla tavalla]
O R: “Kato, nii te ootte noin ja sit... [Merkkaa käsillään radan linjaa.] Ajatat…
O1/Alex: Leo varo varo varo… [Pojat yrittävät asettaa mittanauhaa.]
O R: “Leo, Leo… Kato. Leo, Leo…”
O2/Leo: [Nostaa katseensa.] “Mitä?”
O R: [Osoittaa] “Täältä tänne… Noin, ei…”
O2/Leo: “No… Äsken sä sanoit et pitää laittaa tästä.”
O R: “En mä sanonu.”
O1/Alex: “Leo toi on sun, toi on…”
O R: [Osoittaa vielä linjaa ja sanoo jotain mistä ei saa selvää.]

T R: “I didn’t say.”
S1/Alex: “Leo that is yours, that is…”
T R: [Points at the line and says something inaudible.]
S1/Alex: “Look these are similar, Leo! Look! [Leo is repositioning the tape measure.] I do it like this. [Takes the lamp in hand, charges the vehicle.] It’s not working…” [Tries again.]
S2/Leo: “This is not a competition…” [Sets the tape measure.]
S1/Alex: “Yeah I'm trying like that... [Loads the car.] This goes back, the two go backwards mine goes forwards... Are you sure it starts... [Rest is inaudible. Takes the lamp and tests if it reaches the whole way]. Hey, now it goes! Look!”
S2/Leo: “There you go.”
S1/Alex: “Leo!” [Inaudible.]
Cameraperson: “It reaches just fine.”
S2/Leo: “Yeah…” [Leo has set the flags at the start and end of the track, takes off the tape measure.]
S1/Alex: “I’ll try!”
S2/Leo: “Now the track is ready, which one was mine?” [Points at the vehicles.]
Cameraperson: “Will you take time? Do you have cell phones?”
S1/Alex: “Wait ... Cell phones ... I don't have a cell phone.” [Patting his pockets.]
S2/Leo: [Takes a cellphone from his pocket.] “Which one was mine?”
S1/Alex: “Umm, this is yours.”
S2/Leo: “This.”
S1/Alex: “No this, this was yours.”
[Alex puts his vehicle at the starting place, Leo prepares to take the time.]
S1/Alex: “Okay.”
S2/Leo: “Wait a second so…” [Rest is inaudible.]
S1/Alex: “Those are a little on the way. [Moves extra gear out of the way.]
O1/Alex: “Kato nää on samanlaisii Leo! Kato! [Leo asettelee mittanauhaa uudelleen.] Mä teen näin. [Ottaa lampun käteensä, lataa autoa] Ei tää toimi…” [Yrittää uudestaan.]
O2/Leo: “Tää ei oo mikään kilpailu…” [Asettaa mittanauhaa.]
O1/Alex: “Njoo mä yritän sillein… [Lataa ajoneuvoa.] Tää menee taakse, kaks menee taaksepäin mul menee eteenpäin… Ootsä ihan varma et se lähtee… [Lopusta ei saa selvää. Ottaa lampun käteen ja kokeilee yltääkö se koko matkan ajalta.] Hei tää menee! Kato!”
O2/Leo: “Noni.”
O1/Alex: “Leo!” [Ei saa selvää.]
Kuvaaja: “Se ylettää just hyvin.”
O2/Leo: “Jes…” [Leo on asetellut liput radan alkuun ja loppuun, ottaa mittanauhan pois.]
O1/Alex: “Mä koklaan!”
O2/Leo: “Nyt on rata valmiina, kumpi näist oli mun?” [Osoittaa ajoneuvoja.]
Kuvaaja: “Sit otattekste aikaa? Onks teillä kännykät?”
O1/Alex: “Odota… kännykät… mul ei oo kännykkää” [Taputtaa taskujaan.]
O2/Leo: [Ottaa kännykän taskustaan.] “Kumpi oli mun?”
O/Alex: “Ööö, sun on tää.”
O2/Leo: “Tää.”
O1/Alex: “Eiku tää, tää oli se sun.”
[Alex asettaa ajoneuvonsa lähtöpaikalle, Leo valmistautuu ottamaan aikaa.]
O1/Alex: “Okei.”
O2/ Leo: “Oota hetki nii…” [Lopusta ei saa selvää.]
O1/Alex: “Noi on vähän edessä.” [Siirtää ylimääräiset välineet pois tieltä.]
Kuvaaja: [Naurahtaa.] “Noni onpa jännää…”
O2/Leo: “Sitte…”
O1/Alex: “N-Y…”
O2/Leo: “Venaa! Noni…”
Kuvaaja: “Ajanlaskija sanoo.”
O1/Alex: “N-Y-T…”
O1/Alex ja O2/Leo: “Nyt!”

| | |
|---|---|
| Cameraperson: [Laughs.] “Well, this is exciting…”<br>S2/Leo: “Then…”<br>S1/Alex: “N-O…”<br>S2/Leo: “Wait! Okay…”<br>Cameraperson: “The timekeeper says.”<br>S1/Alex: “N-O-W…”<br>S1/Alex and S2/Leo: “Now!”<br>S2/Leo: “No, not yet. N-O-W now! This won't start … Oh wait…”<br>S1/Alex: “This too won’t start!”<br>Cameraperson: “Okay.”<br>S1/Alex: “Okay!” [Vehicle starts moving.]<br>Cameraperson: “Put… yeah.”<br>S2/Leo: [Inaudible.] “Wait…”<br>S1/Alex and S2/Leo: “N-O-W Now!” [Alex starts driving the vehicle with the lamp, Leo takes the time.]<br>Cameraperson: “Yeah… Wow…”<br>S1/Alex: “What was it?”<br>S2/Leo: “5:85.”<br>[Alex claps.]<br>Cameraperson: “Great.”<br>S1/Alex: “Yeah!”<br>S2/Leo: “Then we take…” [Moves the other vehicle to the starting place.]<br>Cameraperson: “Should you write it down?”<br>S2/Leo: “We have to take the, we have to take the video!” | O2: “Eiku, ei vielä. N-Y-T Nyt! Tää ei käynnisty… Eiku ainii…”<br>S1: Ei tääkään käynnisty!<br>Kuvaaja: “Noni.”<br>O1/Alex: “Noni!” [Ajoneuvo lähtee liikkeelle.]<br>Kuvaaja: “Laitas… juu.”<br>O2/Leo: [Ei kuulu kunnolla.] “Odota…”<br>O1/Alex ja O2/Leo: “N-Y-T Nyt!” [Alex lähtee kuljettamaan ajoneuvoa lampun avulla, Leo ottaa aikaa.]<br>Kuvaaja: “Jes… Vau…”<br>O1/Alex: “Paljo?”<br>O2/Leo: “5:85.”<br>[Alex taputtaa.]<br>Kuvaaja: “Loistavaa.”<br>O1/Alex: “Jes!”<br>O2/Leo: “Sit otetaan…” [Siirtää toisen ajoneuvon lähtöpaikalle.]<br>Kuvaaja: “Pitääks toi kirjottaa jonnekki ylös muistiin?”<br>O2/Leo: “Tästhän pitää ottaa se, tästhän pitää ottaa se video!” |

In this episode, Alex gets the idea to hold a competition while testing the solar-powered vehicle. His proposal created a spark for the emergence of students’ transformative agency. With the help of the teacher, the students designed and worked together to implement their ideas for organizing the competition. Although the race ended up halfway, this example shows the students using the tools of the challenge to commit to taking concrete actions to pursue a design and making activity that met the students’ interests.

## 7.3 Summary of results

In the analysis of the expressions of students' transformative agency, I applied the six types of transformative agency according to the classification of Haapasaari and colleagues (2016): resisting, criticizing, explicating new possibilities or potentials in the activity, envisioning new patterns or models of the activity, committing to concrete actions and taking consequential actions to change the activity (Haapasaari et al., 2016). I identified expressions of students' transformative agency connected to each type and described them with an excerpt from the data.

Resisting and criticizing were manifested as resisting a change in action or current action by means of playing, refusing to work, fooling around, or behaving in a disruptive manner. The student's actions revealed sparks of emerging transformative agency as they disengaged from the instructions. Explicating new possibilities or potentials in the activity and envisioning new patterns or models of the activity were manifested in the students' activities as pursuing their own interests and extending the instructions for challenges. With the planning of their own designs, the emergence of students' transformative agency progressed. Committing to concrete actions and taking consequential actions to change the activity were manifested as students creating meaningful design and making activities for themselves, refining the finished design or using the framework of the challenge to realize their own artifacts. The students broke away from what they were expected to do and collaboratively realized their own design and making interests.

In most of the expressions of transformative agency that I identified, students worked using physical tools. Building on the types and features of transformative agency presented above, I identified three types of roles for the tools: tools arousing curiosity and playfulness, that was mostly seen in connection to resisting and criticizing; tools inspiring imagination of new possibilities, that was occurred in the context of explicating new possibilities or potentials in the activity and envisioning

new patterns or models of the activity; and tools as facilitators of students' alternative design and making activities, that appeared especially in episodes of students committing to concrete actions and taking consequential actions to change the activity. I described the use of tools in connection with the expressions of students' transformative agency with examples.

# 8 Reliability and ethical considerations

In this chapter, I will address the reliability and ethical considerations of this research.

## 8.1 Reliability

There are no clear criteria for assessing the reliability of qualitative research. Traditionally, the concepts of reliability (reproducibility of results) and validity (the study has examined what was meant to be studied), which have been associated with quantitative research, are hardly used in the context of qualitative research, as they are thought to include the assumption of one concrete reality that is sought with the research (Tuomi & Sarajärvi, 2018). Instead, in qualitative research, the researcher evaluates the reliability of the research continuously and simultaneously during the research process (Tuomi ja Sarajärvi 2018; Eskola & Suoranta, 1998). In the research process, the essential points for quality assessment are the object and purpose of the research, the reporting of one's own commitments, the collection and analysis of data and the reporting of the research (Tuomi & Sarajärvi, 2018).

The aim of this study was to identify and describe the expressions of transformative agency in the context of a novel design and making environment, namely the FUSE Studio, analyzing video data. Qualitative data contains a lot of interesting information, along with which it is especially important to choose a narrowly defined phenomenon and select from the material only the sections dealing with this phenomenon. (Tuomi & Sarajärvi, 2018). This study was inspired by the lack of previous studies on the subject of children's transformative agency (for exception see: Kajamaa & Kumpulainen, 2019). The topic was chosen together with the study supervisors.

I had the opportunity to use the video footage filmed for a research project "Learning by Making": The Educational Potential of School-based Makerspaces for

Young Learners' Digital Competencies" (iMake, project no: 310790), led by Professor Kristiina Kumpulainen and funded by the Academy of Finland. Personally, I am not involved in that project and therefore I was not involved in the data collection. Instead, I utilized the content log created by a member of the research group as a basis, as I watched and analyzed the 75 hours of video data collected in the fall of 2016. The fact that I wasn't there personally to collect the data, might have affected the interpretations I have made regarding the expressions of students' transformative agency. Had I been present at the sessions to follow the students' actions, my understanding of the emergence of their transformative agency would certainly have evolved to be more multidimensional.

The data used in this study was collected by filming teachers' and students' work in the FUSE Studio. The benefits of using video for data collection are that it allows for an accurate description of events as its bias is consistent and doesn't rely on human interpretation. A video recording can also be viewed an unlimited number of times, by multiple researchers, in slow or accelerated motion, that makes it possible to make observations that might otherwise go unnoticed. (Jordan & Henderson 1995.) Still, there is always a person behind the camera. The choices made by the operator are limitations to video recording, because by pointing the camera and choosing the location of the microphone, the operator decides what is shown or heard in the video. (Jordan & Henderson 1995.) As I was not involved in the data collection, the choices made in the field were made by researchers that had their own agenda. However, the data, 75 hours of video covering the entire fall semester, can be considered extensive. It has also been analyzed from many different perspectives by multiple researchers, so I see it applicable to this study as well.

I approached the data using a whole-to-part inductive procedure, beginning the analysis by viewing the video corpus with loose classifications and continuing to refine the categories applying a theoretical framework of types of transformative agency created by Haapasaari and colleagues (2016). (Derry et al., 2010; Haapasaari et al., 2016). The features of the types of student's transformative agency in this study were defined and redefined several times as the analysis

progressed. Not all manifestations of students' transformative agency had necessarily been obtained entirely on tape. The camera could be focused on capturing a group of students who decided to move out of view while working. Some of the cameras, in turn, monitored the teacher's activities, so as the teacher moved away from certain students, it was no longer possible to follow the development of their activities. However, in my view, the fact that the expressions of students' transformative agency were broadly consistent with previous studies, such as the study of Kajamaa and Kumpulainen (2019), that identified three types of manifestations of students' transformative agency, namely deviating, switching and transfiguring, in the context of the FUSE Studio (Kajamaa & Kumpulainen, 2019), increases the reliability of this study.

Regarding the second research question, the role of tools as mediators of students' transformative agency, the findings of this study place particular emphasis on the physical tools, as in related episodes I was able to observe visible and audible student activity, while working on digital challenges was quieter and often more independent. Therefore, the importance of the use of digital tools in the emergence of students' transformative agency cannot be reliably assessed by this study.

To further increase transparency, I used examples transcribed from the data to illustrate the presentation of the findings. I present the examples in parallel in Finnish and English so that the reader has the opportunity to assess the reliability of the translation I have prepared. (Nikander, 2010). Finally, in the research report I have sought to present the decisions made during the research process openly so that the reader has the opportunity to evaluate the reliability of the work throughout the text.

## 8.2 Ethical considerations

According to Tuomi and Sarajärvi (2018), research ethics is related to the quality and reliability of research. In qualitative research, there are different ways of ap-

proaching research ethics. At one extreme, research ethical problems are considered to be related to the implementation of the research itself, and the research methodology is understood mainly as a strategic dilemma for solving research problems. At the other extreme, research ethics is seen as a methodological issue, in which case the choices made in research are seen as moral choices. (Tuomi & Sarajärvi, 2018.) As I have noted above, I was not personally involved in the research project, of which the data I have used in this study was collected. I will therefore report on decisions regarding the research ethics made in relation to the collection of the data, on the basis of my discussions with the members of the research team, as well as the articles and master's theses they have written. However, the ethical issues associated with data analysis and reporting of the findings I have considered throughout this research process.

According to Kuula (2015), the institutions or organizations in connection with which the material is collected may be the gatekeepers of the research from the researcher's point of view. Before a research permit can be applied for from the organization under investigation, the research, especially in the public sector, often requires a favorable opinion from the administrative bodies on the research plan. (Kuula, 2015.) For the data used in this study, the research group that collected the data applied and received for permission from the City of Helsinki and the principal of the school under study.

Participants in the study should be asked permission to videotape and explain the purpose of the filming (Pink, 2007). Children belong to special groups protected by law, whose participation in the study is decided by the guardian, as they do not have the right to determine their participation in the study. (Kuula, 2015; Derry et al., 2010). The research team whose data I utilize in this study asked students' guardians for consent for the student to participate in the study before data collection began. According to Kuula (2015), protection can also turn into a representative exercise of power, so that the children themselves are not asked for their consent separately, but it is thought that the preliminary consent obtained from the parents is final and sufficient. Thus, for example, in school-based studies, the student may not dare to refuse and may feel compelled to participate in

the study for which his or her guardian has given consent. (Kuula, 2015.) During the first FUSE sessions a member of the research group informed the students about the research and they were explained why their activities were being filmed and who would watch the videos. Individual students or groups of students that were filmed, were also asked permission to record for each session separately and they had the opportunity to refuse.

Derry and colleagues (2010) raise the issue of sharing data outside the original research team. They suspect that as data passes from hand to hand, its use may begin to take unpredictable directions. New users may not have a broad enough understanding of the context and boundary conditions in which the data was originally collected, which may lead to skewed results. This can be prevented by an appropriate description and reference of the research context. (Derry et al., 2010.) As I have previously reported, I am not part of the research group that compiled the original data. However, the study has been guided by senior members of the research team with whom the context of the study, data collection, and results reported in other studies were discussed.

The privacy and confidentiality of the subject are key concerns in gathering and analyzing research data from which individuals may be identifiable (Derry et al., 2010; Kuula, 2015). In the analysis of qualitative data, a common way of anonymization is to remove or change proper names into pseudonyms (Kuula, 2015). In this study, I have changed the names of students and teachers into pseudonyms, so that individual participants cannot be identified. In addition, the name of the school is anonymized in the school curriculum document.

# 9 Discussions and conclusions

In this chapter, I will discuss the findings of this study and compare them to existing literature in order of the research questions related to expressions of students' transformative agency and tools role in its emergence. The Conclusions section addresses the significance of the results as well as the limitations of the study. Finally, I make suggestions for future research.

The introduction of the FUSE studio, a novel design and making environment, in the school under study responded to the objectives of the new curriculum for the development of new, diverse learning environments that utilize technology and support student participation and joint problem-solving. By analyzing the video data and using purposeful sampling, I identified the expressions of students' transformative agency in the FUSE Studio (see Table 1). In the analysis, I applied the classification of six types of transformative agency by Haapasaari and colleagues (2016) as a frame of reference. Expressions of students' transformative agency were found especially in episodes where students worked on challenges that utilized physical tools. I identified three types of roles that the tools had in the emergence of students' transformative agency.

## 9.1 Expressions of students' transformative agency

This study was conducted in the context of the FUSE Studio, a novel design and making environment aimed to promote STEAM learning through joint problem solving and supporting student agency and relative expertise. Engeström (2011), and Haapasaari and colleagues (2016), in turn, studied adults' transformative agency in the context of the Change laboratory, a formative intervention method. Consequently, the examples they used to illustrate the expressions of transformative agency were quite different from the students' expressions of transformative agency found in this study. Therefore, the analysis of the data was problematic from time to time. In interpreting students' expressions of transformative agency, I seek to emphasize the contradictions and motives behind transformative

agency, rather than looking for similar examples that are similar to those in previous studies. For instance, in the study of Haapasaari and colleagues (2016), the example for committing to actions was: *“We will model the metrics so that they are ready by the end of January. They will then be presented to the management and everybody in this group”* (Haapasaari et al., 2016, 242). In this study, I interpreted a student expressing committing when he said in example 5: *"Um ... I'm going to ask for the tape."* Even though not explicitly stated, the student’s commitment to start building tunnels, and thus changing the activity, is, in my view, clearly visible.

The results of this study have similar elements to those of other studies on agency in the context of the FUSE Studio, that utilize the work of Engeström (2007) or Haapasaari and colleagues (2016) as a theoretical background. Next, I compare my study with the research of Kumpulainen and colleagues (2018) about the agency-structure dynamics, and the research of Kajamaa and Kumpulainen (2019) about students’ transformative agency in the FUSE Studio.

Kumpulainen and colleagues (2018) applied Engeström’s (2007) conceptualization of stabilization knowledge and possibility knowledge to study educational change through agency-structure dynamics. They argue that with the introduction of the new learning environment, a boundary space, where “traditional teacher-centered activity patterns interacted and came into tension with student-centered modes of teaching and learning”, was created. They found three distinctive agency-structure dynamics, namely maintaining existing patterns of activity, breaking away from existing patterns of activity, and collective uptake of new patterns of activity. (Kumpulainen et al., 2018, 26.) In the same vein, Kajamaa and Kumpulainen (2019) found three types of manifestations of student agency, namely deviating, switching and transfiguring, while studying the temporal development of students’ transformative agency (Kajamaa & Kumpulainen, 2019).

Maintaining existing patterns of activity, as described by Kumpulainen and colleagues (2018), refers to drawing on stabilization knowledge and maintaining the traditional school culture (Kumpulainen et al., 2018). I understand this as the

baseline against which the expressions of the students' transformative agency are considered. The first type of students' transformative agency found by Kajamaa and Kumpulainen (2019) is deviating, which describes situations in which "the students expressed criticism, frustration and/or dissatisfaction toward the instructions given by their teacher(s) or by the FUSE website discursively, or by other actions, simultaneously demonstrating a will to depart from those and to act in another way, more meaningful to them" (Kajamaa & Kumpulainen, 2019, 270). I consider this to be in line with resisting and criticizing, which in this study are manifested in students opposing initiatives to transform the activity, refusing to work or acting in a disruptive way and students showing uncertainty, playing and tinkering with tools, fooling around and opposing current activities. Based on these descriptions, I would conclude, that the process of students' transformative agency begins with a spark that either goes out, leaving students to act and work according to the instructions given, following the traditional school culture, or ignites, when students make their first change acts.

Next, the agency-structure dynamics of breaking away from existing patterns of activity, refers to students using possibility knowledge in their agentive action in situations, where they were working with challenges meaningful to them. This was manifested in the students' disregarding the original demands of the FUSE Studio. However, as these actions were not accepted by the teachers, the tension remains between the teachers' actions and the students' motives. (Kumpulainen et al., 2018.) The description of this stage is parallel both to the switching of the Kajamaa and Kumpulainen (2019) study, and to the types of explicating new possibilities or potentials in the activity and envisioning new patterns or models of the activity. Switching is described as "the group members experimenting with new roles, with an overall aim to progress with the challenge independently from the teacher and the instructions, transforming the learning task to fit the student's needs in a certain, meaningful way" (Kajamaa & Kumpulainen, 2019, 270). In this study the types of explicating new possibilities or potentials in the activity and envisioning new patterns or models of the activity took the form of students' extending the given instructions by planning and explaining creative acts or use of tools in an unexpected way and in students planning to deviate from instructions

in pursuit of their own interests. Thus, the focus of this phase would appear to be on the progress of the student agency process through tentative experimentation with students' own interests.

Last, with the agency structure of collective uptake of new patterns of activity, students break away from the structure of the FUSE Studio. Drawing from possibility knowledge, the students direct their work toward their own interests beyond the challenge. (Kumpulainen et al., 2018.) Exceeding instructions and expectations is also a key factor in the manifestation of transfiguring recognized by Kajamaa and Kumpulainen (2019) and in the features of students' transformative agency found in this study. Transfiguring was seen in students "legitimizing and sustaining the new solutions and the transformed roles of the participants" (Kajamaa & Kumpulainen, 2019, 270–271). The descriptions above reflect the features of students' transformative agency connected to committing to concrete actions and taking consequential actions to change the activity. In this study, they are manifested in students' committing to materializing ideas into alternative solutions and creating an alternative design and making activity that met the students' interests. Although the development of transformative agency is not a linear, but a constantly evolving process based on contradictions (Kajamaa & Kumpulainen, 2019), at this stage it can be considered that students' transformation has ignited properly and is guided by their own interests instead of outside guidelines or structures.

According to Hilppö & Stevens (2020), "A key goal of FUSE Studios is to act as an entry point or 'on-ramp' for students to discover and develop new interests— or further develop existing interests brought from out-of-school pursuits— through activities in what have come to be called STEAM areas (i.e. science, technology, engineering, arts, and mathematics)" (Hilppö & Stevens, 2020, 3). To achieve this goal, the development of the FUSE Studio is based on five core design features. One of the core design features is allowing students to choose the challenges they want to work on, and where, how and with whom they want to work. (FUSE Studio, 2020; Hilppö & Stevens, 2020; Stevens et al., 2016.) At the time of data collection, the FUSE Studio had just been introduced in the researched school,

so the students as well as teachers were still navigating the new ways of working and learning. Nevertheless, the findings of this study, which corroborate the findings of Kumpulainen and colleagues (2018) as well as those of Kajamaa and Kumpulainen (2019), demonstrate that student agency is indeed supported in the FUSE Studio. I hold that, moreover, expressions of students' transformative agency are found in the FUSE Studio, which I have demonstrated with a variety of examples.

## 9.2 Tools mediating students' transformative agency

Another aim for this study was to describe the role of tools in the emergence of students' transformative agency. The analysis was done by sampling the videos and identifying episodes, in which the tools had a pivotal part in mediating the change in the students' actions. Three kinds of roles were found, namely tools arousing curiosity and playfulness, tools inspiring imagination of new possibilities, and tools as facilitators of students' alternative design and making activities. The roles were presented in connection to the expressions of transformative agency.

Tinkering, a hands-on making activity that promotes creative interdisciplinary investigations based on students' interests, is an essential part of a maker education. The student's use of physical tools in the FUSE Studio reflect the tinkering-supported learning dimensions of engagement, initiative and intentionality, social scaffolding, and development of understanding identified by Bevan and colleagues (2014) in the context of a museum-based Tinkering Studio. (Bevan et al., 2014.) The dimension of engagement and its manifestations of playing, envisioning, making, exploring materials and trying this over and over (Bevan et al., 2014), were very similar to the expressions of transformative agency the students showed in this study and reflect especially well the tools' role as arousing curiosity and playfulness. The dimension of *initiative and intentionality* that manifests as planning steps for future action and developing unique strategies, tools, objects and outcomes (Bevan et al., 2014), was in this study seen in students being inspired by tools to imagine new possibilities. The manifestations of *social scaffolding*, for example requesting and offering ideas and approaches and offering tools

or materials in service of an idea (Bevan et al., 2014), were evident in almost all episodes where a group of students worked together. For instance, example 9 describes how, with a teacher supporting a hands-on learning experience on the concept of speed, two students built an understanding of how a race can be organized using only one vehicle. Students demonstrated, transferred and negotiated the possible use of tools in an effort to realize their plans. Lastly, the manifestations of the learning dimension of *development of understanding*, offering or refining explanations for a strategy tool or outcome, possibly by testing and retesting and remaining in the problem space to explore their confusion and to build an understanding (Bevan et al., 2014), are seen in example 8, where a student and a teacher are solved a problem with a solar-powered vehicle.

In the activity-theoretical approach, which this study follows, tools and signs have an important part in mediating voluntary actions (Engeström, 2005). The development of transformative agency is often interpreted through Vygotsky's method of double stimulation. According to Sannino and Laitinen (2015), the method of double stimulation "refers to the mechanism with which human beings can intentionally break out of "meaningless situations" and transform them" (Sannino & Laitinen, 2015, 4). The first stimulus refers to a task, a problem, a contradiction or a conflict of motives that is sought to be resolved through the introduction of a mediating artifact, that is, the second stimulus. The second stimulus refers to artifacts that, for example, help organize behavior or allow an individual or a group to approach a situation in a new, potentially expansive way. (Thorne, 2015; Virkkunen, 2006; Engeström & Sannino, 2010.) In this study, features of double stimulation are present in all the three types of roles that I identified the tools to have in mediating the emergence of students' transformative agency in the FUSE Studio. For all three roles, the first stimulus often manifested itself in a conflict between the student's own interests and the instructions or expectations of the learning environment or as a problem to be solved related to the challenge. The second stimulus, in turn, was often one of the tools associated with the challenge or found in the classroom.

Within the tool's role as arousing curiosity and playfulness, the resolving of tensions between the student's own interests and the instructions or expectations of the learning environment sometimes appeared in students fooling around or using the tools to disrupt other students' work. At times, as in Example 7, the introduction of the second stimulus, a marshmallow, aroused enthusiasm in the student for the new use of the tool, whereby tension was resolved by the student changing her activities to better match her interests. However, "the process was predominantly oriented to specific criticisms and stepwise practical improvements rather than to a radical overall change of the object and model of the activity", so regarding the emergence of transformative agency, the students' change actions remained mainly at the preliminary level (Haapasaari et al., 2016, 258).

Related to the second identified role of tools, inspiring imagination of new possibilities, the first stimulus, the contradiction or a problem, was sought to be resolved by envisioning alternative activities and use of tools. In example 8, the first stimulus was a challenging task, in this case a solar powered vehicle that was not working properly. The second stimuli; neutral external artifacts, which the subject turns into mediating signs by filling them with meaning related to the problem situation, were a white copying paper and a capacitor (see Picture 2). The second stimuli help the student to gain control of their action and a new understanding of the problem situation, thus resolving the contradiction. Furthermore, the tools inspire the student and teacher to experiment with the tools and envision alternative ways to complete the challenge, thus advancing the development of a process of shared transformative agency between the student and the teacher.

Regarding the third role of tools as facilitators of students' alternative design and making activity, the first stimulus also appeared in particular as tensions between students' interests and the instructions of the FUSE Studio. In example 9, the second stimulus was a cell phone used by students to measure the time it took a car to travel a certain distance. The cellphone allowed the students to organize the intended race and thus resolve the contradiction between the students interests and the instructions of The FUSE Studio in a way that ended in the students breaking away "from their current way of thinking and acting, and to begin to

transform the activity system collaboratively through experimenting with new tools and new kinds of productive actions" (Virkkunen, 2006, 52).

Kumpulainen and Kajamaa (2019), researched social objects in the FUSE Studio and found that "material objects of the makerspace turned to social objects via joint attention and social interaction *about* the objects, *around* the objects and *with* the objects" in three interactional processes. (Kumpulainen & Kajamaa, 2019, 354.) The first process, about the objects, is in this study connected to the tools' role as arousing curiosity and playfulness. In this process, the students use the objects or tools to experiment and familiarize themselves with the challenges (example 2). There is no example described separately for the second process, around the objects, in this study, but situations were found in the data where, for example, students played on their phones. However, the third process "in which joint attention was established and maintained *with* the material objects" (Kumpulainen & Kajamaa, 2019, 357), was prominent in this study. For instance, the episode where the two boys built large marshmallow structures (example 6) or the one where the boys set up a race (example 9), depict how the students work is inspired and carried out with the tools thus mediating the students' engagement.

The findings also support and extend the notions of tools found in the Ramey and Stevens (2019) study. In their research on the relation between interest development and learning in the context of the FUSE Studio, they discovered that sometimes instead of the topic itself, students are interested in something surprising. In the case of their study, a student pursued an interest in 3D printing and instead of working on the challenges, she spent the school year increasing her expertise in it. (Ramey and Stevens, 2019.) Although this study did not have a similar temporal dimension, a connection in the notions of the tools mediating students' transformative agency can be seen. The tools inspired the students to see new potential activities (example 9) and triggered the students (example 4) to explore their own interests beyond the instructions and facilitated collective creative output.

## 9.3 Conclusions

In this study, I describe the features of students' transformative agency, and the role of tools in its emergence, in the context of a novel design and making environment. There is little existing research on the subject, so this study will increase understanding of the topic. I illustrate how the non-linear process of transformative agency begins with a spark, which manifests as students directing their actions toward their own interests. When ignited, the spark of students' transformative agency can sometimes lead to unexpected design and making experiences. Based on the examples described in this study, it would appear that students have taken the core principle of "students choose" behind the FUSE Studio even beyond the goal in many respects. I also argued that physical tools contribute to the emergence of students' transformative agency by arousing curiosity, inspiring, and facilitating change in students' actions. The results of the study are largely in line with previous research literature; however, the perspective on students' transformative agency, rather than traditional adult-centered research, was seen especially in the diversity of expressions of students' transformative agency, which combined verbal and bodily communication.

This study reflects the conception of learning of the National Core Curriculum, which emphasizes the student's role as an active agent. Previous research has shown that a student's personal relationship to the subject matter is strengthened as he or she takes an active role in learning. The active role of the student can be promoted by supporting the students' own meaning-making processes with tasks in which the student has the opportunity to utilize his or her own vision or previous experiences. (Papert, 1980; Resnick et al., 2000; Kafai et al., 2014.) Extending the existing literature, the findings of this study suggest that giving students opportunities to influence their own work can enable them to develop their own creative thinking and agency, and lead to unexpected design and learning experiences. However, it is worth asking whether all students have the prerequisites to operate in such a free learning environment and how students' change acts could be better supported to promote productive activities. The expressions

of transformative agency I have presented in this study are a noteworthy addition to the discussion of students' self-directed activity in novel learning environments. Moreover, in the context of an ever-digitalizing school, the results of this study on the role of physical tools as mediators of students' transformative agency in a novel design and making environment that combines digital and physical materials, provide a valuable counterbalance to technology-emphasizing perspectives.

## 9.4 Limitations of this study

It should be noted, however, that this study has its limitations. First, it was common for the students or groups of students, that were filmed, to vary frequently during the same FUSE session. Hence, there were relatively few videos that would have shown the work of the same students or groups of students throughout the session. Therefore, no conclusions can be drawn from the results of this study regarding the temporal dimension of the development of students' transformative agency. Although I identified all six types of transformative agency described by Haapasaari and colleagues (2016) from the data, the features found in this study related to these have been formed from individual episodes expressing students' transformative agency.

In the same vein, I was not able to address the use of digital tools in mediating the emergence of students' transformative agency. I see this in part as a result of my not being involved in the data collection process. Thus, when analyzing the material purely on the basis of videos, I selected only episodes for analysis the content of which I was able to interpret with reasonable certainty. Many of the situations in which students worked on computers would have, in my view, been too open to interpretation because of the small amount of speech that appeared on them. Therefore, it should not be concluded from the results of this study that only physical tools contributed to the development of students' transformative agency.

Additionally, the contextuality of this study can be considered a limitation. This research was conducted in a school-based design and making environment, the FUSE Studio, so the traditional structures of a school culture with its rules, goals, and power relations are also present in the analyzed sessions. Although the FUSE Studio emphasizes the student's freedom to choose, the learning environment itself, with its challenges and pre-assembled material boxes, is a well-framed and structured space that guides students to act in a certain way.

Finally, the personal experiences and thoughts of students have not been achieved by the methods of this study, so the results must be understood as my interpretation of the events.

## 9.5 Suggestions for future research

With future research, I would suggest addressing the temporal dimension, as well as the role of digital tools in the emergence of students' transformative agency. Also, in my view studying students' own experiences regarding transformative agency would provide valuable insight into understanding the special features of the development of students' transformative agency and its significance. Important future research questions based on this study are the following: How students' transformative agency emerges over time in a novel design and making environment? Is the process of the emergence of student's transformative agency different in traditional learning environments? What kind of roles digital tools have in the emergence of students' transformative agency? How students understand the types of transformative agency? What kind of experiences and thinking can be found in the background of students' transformative agency?

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# Appendix 1: The FUSE Studio Challenges

Coaster Boss

In the challenge, a roller coaster is built on a ball that must be made to pass through the track under certain conditions.

Crystal Ball

The challenge is to program the lights change color as desired.

Dream Home

The challenge is to design a house in 3D using a computer program.

Electric Apparel

The challenge is to attach lights to a garment and build a mechanism by which the lights turn on when the garment is worn.

Eye Candy

The challenge is to design sunglasses and print them using a 3D printer.

Game Designer

The challenge is to use video game design to move a game character.

Get in the Game

The challenge is to design game controllers that can be used to play the game using your own body.

How to Train Your Robot

The challenge is to program a robot to follow commands.

Jewelry Designer

The challenge is to design jewelry using a computer program and print it out in 3D

Just Bead It
The challenge is to grow gel beads using lab-techniques that are used to grow human cells.

Keychain Customizer
The challenge is to design, and 3D print a keychain.

Laser Defender
The challenge is to create a security system using lasers and mirrors.

LED Color Lights
The challenge is to combine and program LED lights.

MiniMe Animation
The challenge is to use 3D animation software to create a character with outfits and moves.

Music Amplifier
The challenge is to build an amplifier.

Party Lights
The challenge is to design, build and program a LED light show.

Print My Ride
The challenge is to design and 3D print model cars.

Ringtones Mix
The challenge is to create a ringtone using an audio mixing software.

Robot Obstacle Course
The challenge is to build an obstacle course using instructions and program a robot through it.

Selfie Sticker

The challenge is to make a sticker self-portrait.

Solar Roller

The challenge is to build and program a solar powered vehicle.

Spaghetti Structures

The challenge is to build structures that meet certain conditions.

Wind Commander

The challenge is to build a windmill that can for example lift objects or make electricity.

3D You

The challenge is to create a 3D model of oneself and print it out on the 3D printer.

# Appendix 2: Data catalog

| Date | Content | Lenght |
|---|---|---|
| **1.9.2016** | Teacher video:<br>students working in the computer classroom | 0:37:56 |
| **1.9.2016** | Student choosing a challenge | 0:05:26 |
| **1.9.2016** | Teacher video:<br>Dream Home: girls and boys , separate computers, in the computer classroom; *How to Train Your Robot*: two boys in the computer classroom | 0:27:32 |
| **1.9.2016** | *Electric Apparel*: two girls in the computer classroom | 0:23:01 |
| **2.9.2016** | Dream Home: two girls in the computer classroom | 0:25:01 |
| **2.9.2016** | Teacher video:<br>teacher instructing students | 0:41:32 |
| **2.9.2016** | Spaghetti structures: three girls in the classroom | 0:46:16 |
| **2.9.2016** | Coaster Boss: three boys in the hallway | 0:31:22 |
| **8.9.2016** | Solar Roller: four girls in the classroom | 0:43:21 |
| **8.9.2016** | Teacher video:<br>Solar Roller: one girl in the computer classroom;<br>Electric Apparel: one girl in the computer classroom;<br>Dream Home: two pairs of girls and one boy, separate computers, in the computer classroom; Ringtones: one boy and one girl, separate computers, in the computer classroom. | 0:46:37 |
| **8.9.2016** | Teacher video:<br>Ringtones: one girl, a pair of girls, and one boy, separate computers, in the computer classroom; Dream Home: several students, separate computers, in the computer classroom; Coaster Boss: six boys in the hallway | 0:35:52 |
| **8.9.2016** | Teacher video:<br>Ringtones: one girl, a pair of girls, and one boy, separate computers, in the computer classroom; Dream Home: several students, separate computers, in the computer classroom; Coaster Boss: six boys in the hallway | 0:40:44 |
| **8.9.2016** | Teacher video:<br>Ringtones: two boys in the classroom; Solar Roller: four girls in the classroom; Dream Home: one boy in the computer classroom; Spaghetti Structures: two boys in the hallway | 0:45:46 |

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|---|---|---|
| **8.9.2016** | Dream Home: three boys and one girl, separate computers, in the computer classroom | 0:40:49 |
| **8.9.2016** | Spaghetti Structures: two boys; Coaster Boss: Six boys; Coaster Boss: two boys, in the hallway | 0:37:51 |
| **8.9.2016** | Solar Roller: three boys in the hallway | 0:29:04 |
| **9.9.2016** | Teacher video:<br>Dream Home: two girls, separate computers, in the computer classroom; Coaster Boss: four boys in the hallway; Coaster Boss: three boys in the hallway; Coaster Boss: three boys in the hallway; Dream Home: one boy in the computer classroom; Dream Home: two boys, separate computers, in the computer classroom; Ringtones: one boy in the computer classroom; Dream Home: one girl in the computer classroom; Spaghetti structures: two boys in the classroom | 0:58:25 |
| **9.9.2016** | Ringtones: one boy in the computer classroom | 0:50:47 |
| **9.9.2016** | Teacher video:<br>Spaghetti Structures: two pairs of girls and three boys in the classroom; Dream Home: eight students, separate computers in the computer classroom; Ringtones: one boy in the computer classroom; Solar Roller: three girls in the classroom | 0:49:51 |
| **9.9.2016** | Students working in the classroom | 0:22:05 |
| **9.9.2016** | Lazer Defender: One boy in the hallway; Coaster Boss: Two boys in the hallway | 0:55:39 |
| **15.9.2016** | Teacher video:<br>Students choosing challenges in the classroom; In the hallway: Coaster Boss, six boys; Coaster Boss: two boys | 0:58:56 |
| **15.9.2016** | Teacher video:<br>Dream home: students working separately in the computer classroom; Ringtones: three girls, separate laptops, in the classroom; Solar Roller: one boy in the classroom | 0:36:52 |
| **15.9. 2016** | Electric Apparel: Two girls in the computer classroom | 1:04:12 |
| **15.9.2016** | Teacher video:<br>Teachers intrructing students, discussing and searching for materials | 0:47:55 |

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|---|---|---|
| **15.9.2016** | Teacher video:<br>Electric Apparel: two girls in the classroom; Ringtones: one boy in the classroom, one boy in the computer classroom; Dream Home: two boys, separate computers, computer classroom; Coaster Boss: two boys in the hallway; Spaghetti Structures: two girls in the hallway; Coaster Boss: six boys in the hallway | 0:56:29 |
| **15.9.2016** | Dream Home: one girl and one boy in the computer classroom, separate computers | 0:45:51 |
| **15.9.2016** | Coaster Boss: two boys in the hallway | 0:48:52 |
| **15.9.2016** | Spaghetti Structures: two boys in the classroom | 0:23:42 |
| **15.9.2016** | Coaster Boss: one boy in the classroom | 0:15:10 |
| **16.9.2016** | Teacher video:<br>Spaghetti Structures: two pairs of girls in the classroom; Solar Roller: one girl on the classroom, two boys in the classroom; Ringtones: one boy in the computer classroom; Coaster Boss: two pairs of boys in the hallway; Solar Roller: two boys in the hallway | 0:53:34 |
| **16.9.2016** | Spaghetti Structures: two girls in the classroom | 0:54:57 |
| **16.9.2016** | Coaster Boss: three pairs of two boys in the hallway | 1:00:12 |
| **22.9.2016** | Teacher video:<br>Ringtones: one boy in the computer classroom; Electric Apparel: one girl in the computer classroom; Solar Roller: three boys in the hallway; Coaster Boss: six boys in the hallway; Spaghetti Structures: two boys in the computer classroom | 0:56:19 |
| **22.9.2016** | Teacher video:<br>Dream Home: two girls, separate computers, in the computer classroom; Solar Roller; two boys and two girls in the computer classroom and in the hallway; Ringtones: one boy in the computer classroom; Ringtones: four girls, separate laptops, in the classroom | 1:00:00 |
| **22.9.2016** | Jewelry Designer: two pairs of two girls in the classroom | 0:50:56 |
| **22.9.2016** | Dream Home: one girl in the computer classroom | 0:53:24 |
| **22.9.2016** | Teacher video: | 0:56:05 |

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|---|---|---|
| | Coaster Boss: six boys in the hallway; Spaghetti Structures: two boys in the computer classroom; Solar Roller: three boys in the hallway | |
| **22.9.2016** | Teacher video:<br>Spaghetti Structures: one girl in the computer classroom; Ringtones: one girl the computer classroom; Dream Home: two boys, separate computers, one girl, in the computer classroom; Solar Roller: one boy in the computer classroom; LED Color Lights: one girl in the computer classroom | 0:52:09 |
| **22.9.2016** | Coaster Boss: six boys in the hallway | 0:52:44 |
| **22.9.2016** | Ringtones: four girls in the classroom, separate laptops | 0:19:10 |
| **22.9.2016** | Solar Roller: two girls and one boy in the hallway | 0:32:40 |
| **23.9.2016** | Teacher video:<br>Electric Apparel: two boys in the classroom; Coaster Boss: two girls in the classroom; Dream Home: two boys, separate computers, in the computer classroom | 0:51:58 |
| **23.9.2016** | Coaster Boss: two boys in the hallway | 0:42:54 |
| **23.9.2016** | Teacher video:<br>Dream Home: two girls, separate computers, in the classroom; Ringtones: one boy in the classroom; Electric Apparel: two girls in the classroom; Dream Home: one girl, in the computer classroom, one boy in the classroom | 0:55:57 |
| **23.9.2016** | Laser Defender: one boy in the hallway; Spaghetti Structures: two boys in the hallway | 0:22:27 |
| **23.9.2016** | Coaster Boss: two girls in the classroom | 0:26:33 |
| **29.9.2016** | Teacher video:<br>Electric Apparel: one girl in the computer classroom, two girls in the computer classroom; Coaster Boss: two girls in the hallway | 0:55:16 |
| **29.9.2016** | Teacher video:<br>Dream Home: two boys, separate computers, in the computer classroom, one boy in the computer classroom; Solar Roller: two girls in the computer classroom, one girl in the computer classroom; Laser Defender: two boys in the hallway | 0:39:57 |
| **29.9.2016** | Music Amplifier: two boys in the computer classroom | 0:52:41 |

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|---|---|---|
| **29.9.2016** | Teacher video:<br>Ringtones: one boy in the computer classroom; LED Color Lights, one boy in the computer classroom; Coaster Boss: four boys in the hallway; Solar Roller: three boys in the hallway: Dream Home: one boy in the computer classroom | 0:41:45 |
| **29.9.2016** | Dream Home: two boys, separate computers, in the computer classroom | 0:45:36 |
| **29.9.2016** | Coaster Boss: four boys in the hallway | 0:55:35 |
| **29.9.2016** | Laser Defender: two boys in the hallway | 0:42:45 |
| **30.9.2016** | Electric Apparel: two girls in the classroom, third girl joins, and they change to Spaghetti Structures | 0:56:33 |
| **30.9.2016** | Teacher video:<br>teacher instructing students | 1:00:25 |
| **30.9.2016** | Teacher video:<br>Ringtones: one boy in the classroom; Coaster Boss: three boys in the hallway; Spaghetti Structures: one boy in the hallway; Laser Defender: two boys in the hallway | 0:56:27 |
| **6.10.2016** | Teacher video:<br>Keychain Customizer: four girls, separate laptops, in the classroom; Solar Roller: three boys, in the computer classroom; Coaster Boss: four boys in the hallway; Spaghetti Structures: three boys in the computer classroom | 0:59:12 |
| **6.10.2016** | Dream Home: Two boys in the computer classroom, separate computers | 0:40:58 |
| **6.10.2016** | Coaster Boss: Four boys in the hallway | 0:58:15 |
| **6.10.2016** | Teacher video:<br>Dream Home: Two boys in the computer classroom, separate computers | 0:40:58 |
| **6.10.2016** | Teacher video:<br>Keychain Customizer, three girls, separate laptops, in the classroom; Dream Home; two girls, separate computers, in the computer classroom | 0:42:11 |
| **6.10.2016** | Teacher video:<br>Dream Home: one girl in the computer classroom | 0:14:16 |
| **6.10.2016** | Teacher video:<br>Teacher instructing students | 0:51:32 |
| **6.10.2016** | Coaster Boss: Four boys in the hallway | 0:56:19 |

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| **6.10.2016** | Laser Defender: Two girls in the hallway | 0:43.13 |
| **13.10.2016** | Teacher video:<br>Solar Roller: one boy in the computer classroom; Electric Apparel: four boys, separate computers, in the computer classroom; Electric Apparel: one girl in the computer classroom; Coaster Boss: four girls in the hallway | 1:02:26 |
| **13.10.2016** | Teacher video:<br>Solar Roller: two boys in the hallway; Dream Home: three girls, separate computers, in the computer classroom; | 0:42:46 |
| **13.10.2016** | Teacher video:<br>teacher instructing students | 0:43:05 |
| 13.10.2016 | Teacher video:<br>teacher motivating a student | 0:08:16 |
| **13.10.2016** | Coaster Boss: Four girls in the hallway | 0:49:43 |
| **13.10.2016** | Solar Roller: Four boys in the hallway; Coaster Boss: Four boys in the hallway | 0:42:46 |
| **13.10.2016** | Teacher video:<br>teacher instructing students | 0:41:32 |
| **14.10.2016** | Teacher video:<br>Dream Home: one girl and one boy, separate computers, in the computer classroom; Dream Home: two boys, separate computers, in the computer classroom; Laser Defender: one boy in the hallway; Electric Apparel: two girls in the computer classroom; Music Amplifier: one boy in the classroom | 0:57:30 |
| **14.10.2016** | Teacher video:<br>Dream Home: one girl and one boy, separate computers, in the computer classroom; Dream Home: two boys, separate computers, in the computer classroom; Laser Defender: one boy in the hallway; Electric Apparel: two girls in the computer classroom; Music Amplifier: one boy in the classroom | 0:52:11 |
| **27.10.2016** | Teacher video:<br>Coaster Boss: three boys in the hallway; Spaghetti Structures: two boys in the computer classroom; Solar Roller: four boys in the hallway | 1:01:08 |
| **27.10.2016** | Teacher video:<br>Music Amplifier: two girls, separate computers, in the computer classroom; Dream Home, one girl in the computer classroom | 0:34:02 |
| **28.10.2019** | Teacher video: | 0:58:11 |

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| | Music Amplifier: one boy in the classroom | |
| **3.11.2016** | Teacher video:<br>Coaster Boss: two girls in the classroom; Dream Home: one girl in the computer classroom; Solar Roller: one boy in the computer classroom | 0:46:55 |
| **3.11.2016** | Teacher video:<br>Dream Home: one girl in the computer classroom; Solar Roller: one boy in the hallway | 0:25:55 |
| **3.11.2016** | Teacher video:<br>Ringtones: one girl in the computer classroom; Jewelry Designer: four girls in the classroom | 0:25:14 |
| **3.11.2016** | Laser Defender: Two girls in the hallway | 0:25:44 |
| **4.11.2016** | Teacher video:<br>Solar Roller: three boys in the hallway; Solar Roller: two boys in the hallway; Laser Defender: three boys and a girl in the hallway; Music Amplifier: ine boy in the classroom; Solar Roller: two boys in the classroom; Dream Home: two girls, separate computers, in the computer classroom; Dream Home, one boy in the computer classroom | 1:01:24 |
| **4.11.2016** | Music Amplifier: One boy in the classroom | 1:02:31 |
| **10.11.2016** | MiniMe Animation: Three girls in the computer classroom, separate computers | 0:46:20 |
| **10.11.2016** | Teacher video:<br>Dream Home: four girls, separate computers, in the computer classroom; Keychain Customizer: four girls, separate laptops in the hallway; How to Train Your Robot: two boys in the computer classroom; Keychain Customizer: one girl in the computer classroom | 0:50:37 |
| **11.11.2016** | Teacher video:<br>Keychain Customizer: two boys, separate computers in the computer classroom; Coaster Boss: two boys in the hallway; Laser Defender: four boys in the hallway; Ringtones: one girl in the computer classroom | 0:58:27 |
| **17.11.2016** | Teacher video:<br>3D You: two girls in the computer classroom; Coaster Boss: four boys in the hallway; Spaghetti Structures: one boy in the computer classroom; unclear challenge: five girls, separate laptops, in the classroom | 0:38:44 |
| **17.11.2016** | Teacher video:<br>Dream Home: one girl in the classroom; Electric Apparel: two girls in the classroom | 0:50:37 |

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|---|---|---|
| **18.11.2016** | Teacher video:<br>Game Designer: two boys, separate computers, in the computer classroom; Laser Defender: three boys and one girl in the hallway; Spaghetti Structures: two girls in the classroom; Dream Home: one girl in the computer classroom; Ringtones: two boys, separate computers, in the computer classroom | 0:56:43 |
| **24.11.2016** | Teacher video:<br>Dream Home: one girl in the computer classroom; Wind Commander: three boys in the hallway | 0:56:28 |
| **24.11.2016** | Teacher video:<br>How to Train Your Robot: two girls in the computer classroom; Dream Home: two girls, separate laptops, in the classroom | 0:45:49 |
| **24.11.2016** | Teacher video:<br>Spaghetti Structures: two girls in the classroom; Wind Commander: two groups of three boys, in the hallway | 0:54:59 |
| **24.11.2016** | Teacher video:<br>Wind Commander: three boys in the hallway | 0:53:51 |
| **24.11.2016** | Wind Commander: Two boys in the hallway | 0:05:57 |
| **24.11.2016** | Students working in the classroom | 0:41:57 |
| **24.11.2016** | Dream Home: One girl in the computer class | 0:43:38 |